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SEPARATION OF DEPLETED URANIUM FRAGMENTS FROM GUN TEST CATCHMENT, VOL III: ECONOMIC COMPARISON OF DEPLETED URANIUM DISPOSAL OPTIONS FOR EGLIN AFB GUN TEST FACILITY

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13. ABSTRACT *(Maximum 200 words)*
This technical report is divided into four volumes. Volume I presents Summary and Recommendations, Volume II contains Catchment System Evaluation and Separating Methods, Volume III contains an Economic Comparison of Disposal Options, and Volume IV documents Bench-Scale Tests for Separation.

Activities are described for a task entitled "Separation of Depleted Uranium Fragments from Gun Test Catchments, Vol. III," sponsored by the Air Force Engineering Services Center, Tyndall Air Force Base, Florida. This volume reports the results of an economic evaluation of five alternative disposal options for contaminated sand. Disposal costs were estimated for the following options of (1) Improved screening, with sand recycle and on-site packaging; (2) Improved screening, with sand recycle and on-site packaging with depleted uranium (DU) fragment recycle; (3) Improved screening, with sand recycle and on-site packaging, with wet separator for derating fines; (4) Improved screening, with sand recycle and on-site packaging, with chemical treatment for derating fines; and (5) Modified test butt; no sand processing. The options "(1) Improved screening, with sand recycle and on-site packaging," is the lowest cost, technically feasible disposal option.

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PREFACE

This report was prepared by Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, DE-AC05-84OR21400, for the U.S. Department of Energy (DOE) and the Air Force Civil Engineering Support Agency (AFCESA), Suite 2, 139 Barnes Drive, Tyndall Air Force Base, Florida 32403-5319.

This report presents the results of a series of activities designed to develop an improved method for separating depleted uranium from target materials, principally sand. Recommendations are offered for the most attractive method from both economic and technical perspectives. The search for an improved method considered the environmental, economic, and technical aspects of the problem. The method of choice is to dry, screen,and recycle the intermediate-sized uranium-contaminated sand. This will save the Air Force an estimated several million dollars over the next 20 years and will reduce the volume of low-level waste by about 90 percent.

This technical report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication,

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EXECUTIVE SUMMARY

OBJECTIVE

The objective of the work described in this series of reports was to develop and demonstrate an improved means for separating depleted uranium from target sand, the source of the uranium being penetrator projectiles fired into a target building containing sand as the stopping medium. The principal incentive is to reduce the disposal costs of the contaminated sand by providing improved separation methods which diminish the waste volume.

BACKGROUND

The engineering and operational test firing of the GAU8 30-mm cannon produces low-level radioactive waste when the depleted uranium projectiles impact the sand contained in the target building. Test hazards and damage to the target building are held to an acceptably low level by periodically removing the large bullets from the sand. Proper operation of the filtration system on the target building roof during firing tests requires periodic elimination of the fine dust generated when bullets impact the sand. A third restriction on the amount of uranium contained in the target building is imposed by the NRC license which limits the amount of depleted uranium on site to 80,000 kg but this limitation has not been the controlling factor in any of the test operations to date.

The present sand removal and treatment operations are of two types. The first is to remove the sand with a front-end loader and sift it through 1/2 inch opening sieve to remove the projectile fragments. The sand is then returned to the target building. With the second method, all the sand is removed from the building and stored on site in drums pending further treatment before shipment for long-term storage at an off-site location. The target building is then filled with fresh sand. These methods are effective but, because of the large volumes sent to storage, are very expensive.

SCOPE

This volume reports the results of an economic evaluation of five alternative disposal options for contaminated sand identified during the early phases of the project. Disposal costs were estimated for the following options:

Option 1 - Improved screening, with sand recycle and on-site packaging.
Option 2 - Same as Option 1, with depleted uranium (DU) fragment recycle.

Option 3 - Same as Option 1, with wet separator for derating fines.

Option 4 - Same as Option 1, with chemical treatment for derating fines.

Option 5 - Modified test butt; no sand processing.

Disposal costs were compared to the current disposal procedure, termed Option 0, and a variant of this procedure, termed Option 0'. The difference between the two is related to the assumed packaging method. Fixation in concrete is assumed for Option 0, as performed in the 1987 disposal campaign, while a loose packaging procedure is assumed for Option 0'.

Guidelines promulgated by the Department of Defense (DOD) and Office of Management and Budget (OMB) were used as the basis for the economic evaluation.

RESULTS

The results of the cost evaluation are given below:

Option	Discounted Life-cycle Costs ($\$ \times 10^6$)
0	5.9
0'	6.3
1	2.0
2	1.5
3	1.7
4	9.1
5	3.3

Options 2 and 3 have not been proven to be completely feasible; therefore, Option 1 is the lowest cost, technically feasible disposal option.

CONCLUSIONS

Option 1, an improved screening procedure which rejects sizes above 10-mesh and below 60-mesh will remove at least 80 percent of the DU from the sand. This procedure, combined with use of similarly presized sand will reduce the volume of material which must be sent for disposal by 90 percent. The discounted life-cycle cost savings realizes by this change are approximately $4.3 million.

RECOMMENDATIONS

The method for improved screening of the target sand with recycling of the intermediate fractions, combined with the use of presized sand for make-up, should be instituted at the present test facility when funding is available for the procurement and installation of the necessary equipment.

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SECTION I
INTRODUCTION

A. OBJECTIVE

The engineering and operational test firing of the GAU8 30-mm cannon produces low-level radioactive waste when the depleted uranium projectiles impact the sand contained in the target building. Test hazards and damage to the target building are held to an acceptably low level by periodically removing the large bullets from the sand. Proper operation of the filtration system on the target building roof during firing tests requires periodic elimination of the fine dust generated when bullets impact the sand. A third restriction on the amount of uranium contained in the target building is imposed by the NRC license which limits the amount of depleted uranium on site to 80,000 kg but this limitation has not been the controlling factor in any of the test operations to date.

The present sand removal and treatment operations are of two types. The first is to remove the sand with a front-end loader and sift it through 1/2 inch opening sieve to remove the projectile fragments. The sand is then returned to the target building. With the second method all of the sand is removed from the building and stored on site in drums pending further treatment prior to shipment for long-term storage at an off-site location. The target building is then filled with fresh sand. These methods are effective but, because of the large volumes sent to storage, very expensive.

B. BACKGROUND

1. Target and Site Description

The gun target consisted of about 500,000 kg (11,000 ft^3) of ordinary sand contained within a reinforced concrete building. The target building and general site layout are described in Reference 2.

2. Operating History and Limitations

The operating history of the gun test facility is summarized in Table 1 (Reference 2) from inception of operation through June 1988. Over this time, the average firing rate was 417 kg DU per month.

Historically, there was one MINOR sand-sifting operation per 5096 kg DU fired and one MAJOR butt cleanout, on the average, following the firing of 15,800 kg DU.

TABLE 1. GUN TEST OPERATIONS HISTORY

Firing period[a]	Fired (kg)	Firing rate (kg/mon)	Cleanout Date	Type
Jan 79-Apr 79	1,932	483	16 Apr 79	Minor[b]
May 79-Oct 79	2,219	370	29 Oct 79	Minor
Nov 79-Jan 80	2,779	926	22 Jan 80	Minor
Feb 80-Jul 80	3,373	562	15 Jul 80	Major[c]
Aug 80-Nov 80	6,067	1517	03 Nov 80	Minor
Dec 80-Feb 82	8,180	545	22 Feb 82	Minor
Mar 82-Mar 84	7,050	282	8 Mar 84	Major
Apr 84-Apr 86	7,271	291	24 Apr 86	Minor
May 86-May 87	6,994	538	4 May 87	Minor
Jun 87-Jun 88	1,719	132	(None)	
Total	47,584			

[a]From the <u>first</u> of the stated month <u>through</u> the final month.
[b]Sand sifted through 1/2-in. screen and returned to butt.
[c]All sand removed, packaged, and shipped to burial.

The MINOR cleanout entails sifting the butt contents are sifted through a screen with 1/2-inch openings for removal of bullet fragments. The fragments are stored for later disposal; the sand and DU fines are returned to the butt. In a MAJOR cleanout, the entire butt contents combined with stored fragments, used air filters, test materials, and other DU-contaminated materials are packaged and shipped for burial.

These MINOR and MAJOR cleanouts alleviate the principal limitations for gun test operation, namely:

a. Accumulation of bullet fragments in the target, which represent a hazard because of ricochets and the potential for fire;

b. Accumulation of fines in the target, which tend to clog the building filters and thus present a site contamination hazard;

c. Accumulation of excessive DU on-site, thereby exceeding the U.S. Nuclear Regulatory Commission (NRC) license limitation of 80,000 kg.

Operational experience has shown that a MINOR sifting following an average of 5096 kg DU fired adequately takes care of the ricochet and DU fire hazard and that a MAJOR sand removal following 15,800 kg DU fired maintains an adequately low fines level. The NRC license limit of 80,000 kg DU on-site is not operationally limiting.

3. USAF Economic Analysis Procedures

The cost studies documented in this report were performed in accordance with Air Force Regulation (AFR) 178-1 (Reference 3) and OMB Circular A-94 (Reference 4). The ground rules for the analysis are summarized below.

a. Benefits - AFR 178-1 differentiates between monetary and nonmonetary benefits. Monetary benefits are revenues and earnings (e.g., cash income). There are no monetary benefits for any of the options considered. Nonmonetary benefits represent utility derived from a project. In this case, the benefit is a target butt for DU projectiles that meets regulatory requirements and other criteria. The benefits are equal for each alternative (i.e., each alternative yields a test butt that stops DU projectiles and meets regulatory requirements).

b. Costs - Costs vary considerably for each alternative. The principal figure of merit is the net present worth of the total life-cycle cost, including (1) capital and start-up costs, (2) fixed operational costs, (3) variable operational costs, and (4) close-down and cleanup costs.

c. Discount Rate - Both AFR 178-1 (Reference 3) and OMB Circular A-94 (Reference 4) prescribe a 10 percent discount rate.

d. Inflation - General inflation was ignored, as prescribed in AFR 178-1 and OMB Circular A-94. General inflation affects the absolute magnitude of cash flows but does not influence the relative ranking of alternatives for a government-funded project.

e. Sensitivity of Results - Both AFR 178-1 and OMB Circular A-94 require sensitivity analysis where appropriate. The results of the sensitivity analysis are presented in Section V.B.

4. Cost Bases

The bases, scaling factors, and assumptions used in determining cost data are included in Appendices A and B. In most cases, the method used to estimate capital costs was based on knowledge of major items of equipment, with cost indices and scaling factors used to adjust for time and size dependencies. Operating parameters and costs estimates were based on historical data for similar operations. This method is known as a "study estimate" and is typically accurate to within ±30 percent (Reference 5).

C. SCOPE

This report provides an economic evaluation of five alternative disposal options for contaminated sand generated at an Eglin Air Force Base (AFB) gun test facility. This work constitutes Phase 3 of the project entitled "Catchment and Separation of Depleted Uranium Projectiles." Disposal costs were estimated for the following five options:

Option 1 —	Improved screening, with sand recycle and on-site packaging.
Option 2 -	Same as Option 1, with depleted uranium (DU) fragment recycle.
Option 3 —	Same as Option 1, with wet separator for derating fines.
Option 4 —	Same as Option 1, with chemical treatment for derating fines.
Option 5 —	Modified test butt; no sand processing.

Each disposal option is fully described in Section III. Options 2 and 3 contain features which have not proven to be feasible and which therefore cannot be fully implemented as described. Option 3 presumes derating of contaminated fines by a wet density separation. However, Phase 2 tests have shown (Reference 1) that while wet separation can provide a large degree of DU removal from sand, it is nevertheless insufficient for the stringent derating standards. In addition, Option 2, as described in Section III, presumes that an outside contractor would process the contaminated sand fines. For a number of reasons, this has proven to be a doubtful step.

Disposal costs were compared relative to the current disposal procedure, termed Option 0, and a variant of this procedure, termed Option 0'. The difference between the two is related to the assumed packaging method. Fixation in concrete is assumed for Option 0, as performed in the 1987 disposal campaign, while a loose packaging procedure is assumed for Option 0'. Department of Transportation (DOT) regulations regarding the loose packaging of sand contaminated with DU metal are discussed in Appendix A.

Guidelines promulgated by the Department of Defense (DOD) and Office of Management and Budget (OMB) were used as a basis for the economic evaluation. Principally, these include:

1. Levelized costs, that is, exclusion of the general inflation rate.
2. Use of a 10%/year discount rate.
3. Sensitivity analysis for the principal uncertainties.
4. Present worth costs for the life of the facility.

A 20-year facility lifetime was assumed, and decommissioning costs were included for all cases. As required, a sensitivity evaluation of the following three uncertain cost parameters was performed: (1) unit burial cost escalation, (2) gun testing rate, in terms of bullets fired per month, and (3) the amount of fine powder produced per bullet fired.

Cost evaluation results are detailed in Section V. A summary of the discounted life-cycle costs for each option is given below:

Option	Discounted Life-cycle Costs ($\$ \times 10^6$)
0	5.9
0′	6.3
1	2.0
2	1.5
3	1.7
4	9.1
5	3.3

As noted above, Options 2 and 3 have not proven to be completely feasible; therefore, Option 1 is the lowest cost, technically feasible disposal option. The above figures indicate that the discounted cost reduction for Option 1 relative to the current disposal procedure is estimated to be $\$3.9 \times 10^6$.

The sensitivity analysis indicates that costs for Option 0 would rise most rapidly, with increases in unit burial costs, relative to the other options. In contrast, life-cycle costs for Options 1, 2, and 3, each of which requires significantly less burial volume than Option 0, are much less influenced on an absolute basis by projected rises in burial fees. A trend that is favorable to Option 0 is a postulated reduction in bullet testing rate. Since there are no capital costs, discounted lifetime costs are reduced approximately proportional to the reduction in testing. The reduction is less for all other options, which require capital investment. However, Option 1 is still projected to be significantly preferred over Option 0, even with an assumed factor of 2 reduction in testing rate.

SECTION II
DISPOSAL OPTIONS

In addition to the current operation (termed Option 0), costs for the following five alternate disposal options are evaluated:

Option 1 -	Improved screening, on-site packaging for burial.
Option 2 -	Same as Option 1, except with DU fragment recycle and contractor disposal.
Option 3 -	Same as Option 1, except wet separator derates fines.
Option 4 -	Same as Option 1, except chemical leaching derates fines.
Option 5 -	Modified test butt, no sand processing.

Option 1 appears to be a technically feasible alternative to Option 0, with significantly lower lifetime cost. The costs and feasibility of fragment recycle to the bullet manufacturer is investigated in Option 2. Also in Option 2, DU and sand fines are packaged and transported under outside contract, much like the 1986-1987 disposal operation.

In Option 3, the volume of disposable waste is reduced by derating the contaminated sand fines using a wet separator. Doing this can reduce packaging and shipping costs, but the requirements for derating are extremely stringent; therefore the technical feasibility of Option 3 is in question.

Option 4 derates fines by a chemical leaching procedure proven on a laboratory scale (Reference 6). However, the difficulty of the method clearly indicates it will not be economically competitive.

Option 5 is patterned after the operations of the Gencorp Aerojet Ordnance gun test facility near Ontario, California. Option 5 uses a butt modification to minimize the effect of fines on the building filter and limit the dispersal of DU fragments in the butt sand. Hence, there is no fines limitation to operation, and the required cleanout volume is smaller than for the other options. Thus, no DU separation step is required, the removed sand being directly dried and packaged.

The following section includes a description of the current disposal process (Option 0) and the five alternatives considered (Options 1-5). The description of each option includes a flowchart, a list of capital equipment, details of the disposal method in regard to radioactive waste, and a brief summary of the decommissioning process.

A. CURRENT OPERATION (OPTION 0)

1. Flow Sheet

Figure 1 is a flow sheet for the current operation (Option 0). A detailed description of the current process is provided elsewhere (Reference 2). The current process includes coarse screening after ~17,000 GAU-8 rounds (5,100 kgs DU) are fired and complete replacement of the sand after ~53,000 GAU-8 rounds (15,800 kgs DU) are fired.

2. Capital Costs

All of the equipment needed for Option 0 is owned by the Air Force or is supplied by the contractor that conducts the cleanup operation. There are no capital costs associated with Option 0.

3. Operating Costs and Procedures

The operating cost elements for Option 0 are summarized in Table 2. The basis for each cost is given in Appendices A and B.

TABLE 2. OPERATING COSTS FOR OPTION 0

Cost element	Cost	Reference
Coarse screening, return sand ($\$/ft^3$ sand)	1.6	Appendix B
Coarse screening, drum sand ($\$/ft^3$)	1.7	
Contract management	200	Actual cost[a]
Site mobilization ($\$ \times 10^3$/major cleanup)	390	Actual cost[a]
Fixation in concrete ($\$/ft^3$ sand)	33	Appendix A
Transportation ($\$/ft^3$ waste)	4.1	Appendix A
Current burial cost ($/ft waste)	37.75	Appendix A
Burial cost escalation (%/year)	6.0	Appendix A

[a]Actual cost from 1986 cleanup operation (R. J. Lynn, Martin Marietta Energy Systems, Inc., letter to A. L. Porell, Martin Marietta Energy Systems, regarding Subcontractor No. 22X-22251V, April 15, 1987).

Option 0 differs from the other options in that the contaminated sand is packaged and shipped every second sand replacement operation. This is done to halve the cost of site mobilization and setup for the concrete fixation equipment for each major cleanup effort.

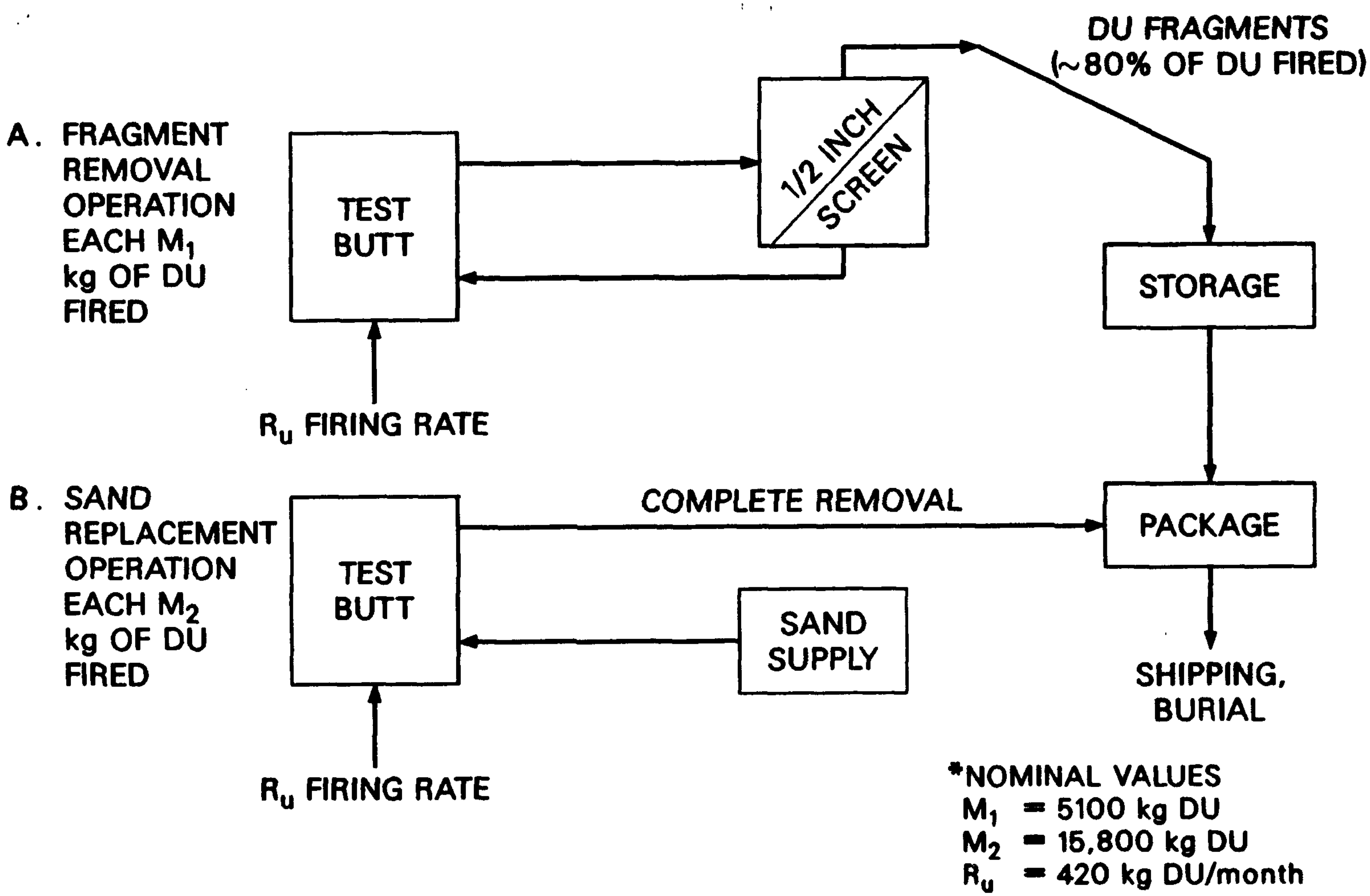

Figure 1. Flow Sheet for Option O.

4. Packaging and Disposal Method

The contaminated sand removed from the butt during a replacement operation is categorized as "uranium metal pyrophoric" radioactive waste (see Appendix A, Section A). The waste is fixed in concrete by mixing with cement and water, placed in 55-gallon drums qualified as Type-A containers (per 49 CFR 173.465), and sent to a commercial radioactive waste burial facility. The DU fragments captured in earlier sifting operations are combined into the solidified mass. As seen in Appendix A, this is an acceptable, though high cost, way of packaging material classified as "uranium metal pyrophoric."

5. Shutdown Method

The decommissioning process for Option 0 includes complete removal and disposal of contaminated sand in the same manner as used in the periodic sand replacements. In addition, contaminated surfaces are cleaned using standard surface decontamination techniques for uranium removal (i.e., washing with soap and water). Materials that cannot be decontaminated to meet standards in effect at the time and contaminated solutions produced in the decontamination process are packaged and shipped to a commercial radioactive waste disposal facility.

6. Variant of Current Operation - Option 0′

Costs for a variation of Option 0 involving a *modified* packaging procedure were also estimated. The variation, termed Option 0′, avoids the concrete fixation step in the packaging procedure. Instead, the contaminated sand is packed loose, directly into Type-A, 55-gallon drums. Appendix A cites the relevant DOT regulations and conditions that permit this sort of packaging.

B. OPTION 1 - IMPROVED SCREENING

1. Flow Sheet

Figure 2 is a flow sheet for a disposal procedure involving improved screening (Option 1). The sand is removed from the butt for coarse screening at the same frequency as used in Option 0 (every 17,000 GAU-8 rounds). The coarse screening cut is taken at 10-mesh (1700 μm) in place of the 1/2-inch screen used in Option 0 to increase the amount of DU removed. Double screening substitutes for the sand replacement operation. The double screening operation is scheduled after ~53,000 GAU-8 rounds (15,800 kg DU) are fired, which is the same frequency used for the current replacement operation. Double screening removes the fragments and fines, resulting in an intermediate size fraction that can be reused as catchment media.

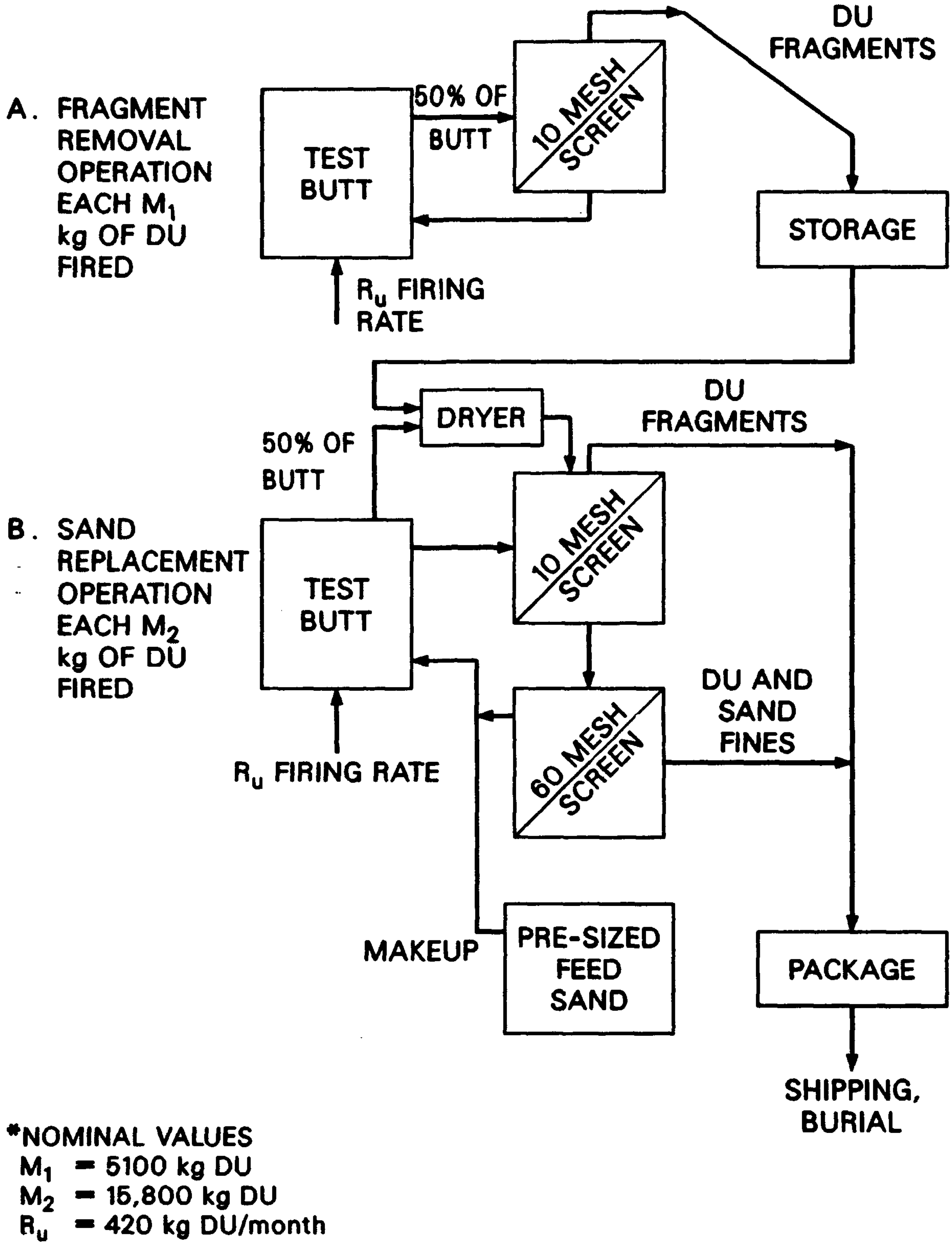

Figure 2. Flow Sheet for Option 1.

An additional departure for Option 1 relative to Option 0 is use of presized sand for the butt-feed material. Presized sand is available from a near-site supplier for approximately \$12/yd^3 compared to about \$10/yd^3 for unsized sand. Ideally, presized sand would consist entirely of the -10/60-mesh particle size range. Therefore, material separated on coarse screening at 10-mesh should consist entirely of DU. An alternate source of presized sand will be available from shakedown operation of the screening equipment. Such operation of the equipment will be required during initial installation and at the beginning of each subsequent cleanout to assure proper setup and operation of the assemblage. The effect on the cost of the option is minor, and no credit is taken for this opportunity in the cost analysis.

The double screening process in Option 1 relieves the existing operational constraints, thereby eliminating the need for complete sand removal as performed in Option 0. The principal operational constraints are

a. DU (and other) fragments must be removed periodically to prevent ricochets.

b. Sand and DU fines must be removed periodically for the HEPA filters to operate effectively.

c. The maximum DU on-site is limited to 80,000 kg by the operating license.

Coarse screens down to 10-mesh remove DU fragments, and a 60-mesh screen removes the fines, leaving an intermediate material that is acceptable for recycle to the butt. The third constraint, total DU on-site, does not impact this option. The estimated quantity of DU in the test butt during an assumed 20-year life is shown in Figure 3. Option 1 will result in an estimated maximum of 13,000 kg DU in the butt at the end of the 20-year life, which represents about 2.5 percent of the butt on a mass basis and about 0.3 percent on a volume basis.

The oversized and fine materials are dried and packaged for disposal. Presized sand is added to the butt to replace the fines that are removed. The principal economic advantage of Option 1 is that only sand/DU fines and DU fragments are sent to burial, reducing the volume of radioactive waste by a factor of 5 to 10.

2. Capital Costs for Improved Screening

The cost of capital equipment needed for Option 1 is listed in Table 3. These cost estimates are study estimates, which are typically accurate within $\pm$30 percent.

3. Operating Costs and Procedures

The operating cost elements for Option 1 are summarized in Table 4. Fragments removed using the 10-mesh screen are stored until a double-screening operation occurs. At that point, fines and fragments are dried, packaged, and sent to the low-level radioactive waste repository.

4. Packaging and Disposal Method

A lower-cost packaging procedure is selected in Option 1 relative to the encapsulation-in-concrete method used for Option 0. As described in Appendix A, a perfectly suitable packaging method for "uranium metal pyrophoric" category material is inerting with dry sand and placement in suitably tested Type-A containers. The most stringent of these tests is the free-drop test, which has been certified to be passed for a 55-gallon drum containing 553 kg (1217 pounds) of wet, loose sand (see Appendix A, Section A). The equivalent composition of dry sand and DU would be about 305 kg (670 pounds) sand and 243 kg (535 pounds) DU, or about 44 weight percent DU. The DU in such a package would represent about 10 volume percent relative to 90 volume percent dry sand. Hence, the inerting requirement would also be satisfied. The fines, DU fragments, and other oversized material are dried, packaged in 55-gallon drums qualified as Type-A containers (per 49 CFR 173.465), and sent to the commercial radioactive waste burial facility at Barnwell, South Carolina (see Appendix A, Section D).

5. Shutdown Method

The decommissioning process for Option 1 includes complete removal, drying, packaging, and disposal of contaminated sand. Contaminated processing equipment and other surfaces would be cleaned using standard surface washing techniques, as described for Option 0 (Section III.A).

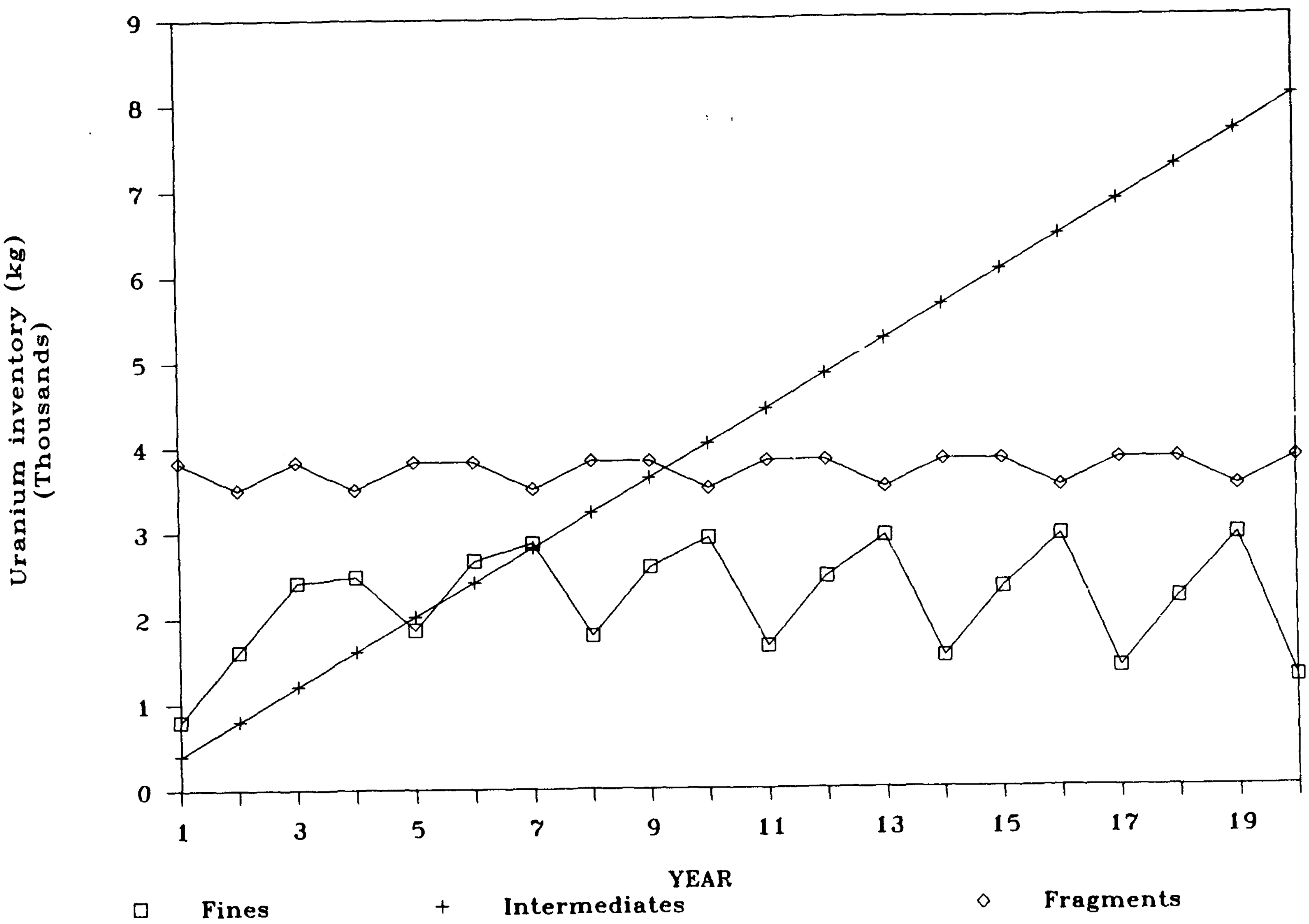

Figure 3. DU Inventory in Test Butt vs Time for Option 1.

TABLE 3. CAPITAL COSTS FOR OPTION 1

Item	Size	FOB cost ($ X 10^3)
Surge hopper	2 yd^3	21
Transfer conveyor	40 ft	22.5
Screening device	5 ft diam	19
Transfer conveyor	40 ft	22.5
Direct fired dryer	3 million Btu/h	98
Baghouse and fan	15,000 ACFM	38.5
Concrete pad pavilion	5,000 ft^2	33
Stacker	60 ft	34
Drum conveyor	60 ft	12
Utilities		140
Assembly		140
Engineering		55.5
Contingency (20% of equipment engineering and assembly		93
Total		599.0

TABLE 4. OPERATING COSTS FOR OPTION 1

Cost element	Cost	Reference
Coarse screening ($/$ft^3$ sand)	1.8	Appendix A
Major cleanup start-up ($ X 10^3)	25	Estimate
Drying and packaging ($/$ft^3$ sand fines)	22.6	Appendix A
Transportation ($/$ft^3$ waste)	4.1	Appendix A
Current burial cost ($/$ft^3$)	37.75	Appendix A
Burial cost escalation ($/year)	6.0	Appendix A

C. OPTION 2 - CONTRACTOR SEPARATION/DISPOSAL AND DU FRAGMENT RECYCLES

1. Flow Sheet

As shown in Figure 4, the flow sheet for Option 2 is identical to that of Option 1 except the manner of packaging and disposal. In Option 2, DU fragments are recycled to a bullet manufacturer, such as Aerojet-General, Inc., Jonesborough, Tennessee. The cost and feasibility of the DU recycle procedure are discussed in Appendix A, Section E.

A second point of departure from Option 1 is the disposal method for the fines. In Option 2, fines disposal is handled under subcontract. So doing can only entail higher costs unless the contractor has the technical capability for derating the fines (as AWC, Inc., of Las Vegas, Nevada, claims to have), thereby diminishing their burial costs.

The fines are dried, packaged, and sent to a contractor for DU separation and disposal. Presized sand is added to the butt to replace the fines that are removed. The contractor is assumed to have the capability to derate the fines by reducing the DU content to <40 ppm while concentrating the DU content in the uranium-rich stream to >50 percent (mass basis). Doing so would result in a significant savings in burial costs.[1]

2. Capital Costs for Contractor Separation Disposal

The equipment needed for Option 2 is largely the same as for Optio 1. However, Option 2 requires the addition of an aluminum/DU density separator in the fragment product stream. This is a requirement of the bullet manufacturer for acceptance of the DU fragments.

3. Operating Costs and Procedures

The operating cost elements for Option 2 are summarized in Table 5. The procedures are identical to Option 1 except that, instead of combining DU fragments and sand fires and shipping the material to burial, the respective streams are sent to a DU manufacturer and sand/DU separation contractor.

4. Packaging and Disposal Method

The packaging procedure for Option 2 is similar to that in Option 1, except that the fragments and fines are kept separate. The DU fragments, classified as "uranium metal

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1 AWC in Las Vegas, Nevada, claims that it is possible to use a physical process to separate sand and DU to this degree. However, AWC has not responded to requests from ORNL for data to support this claim.

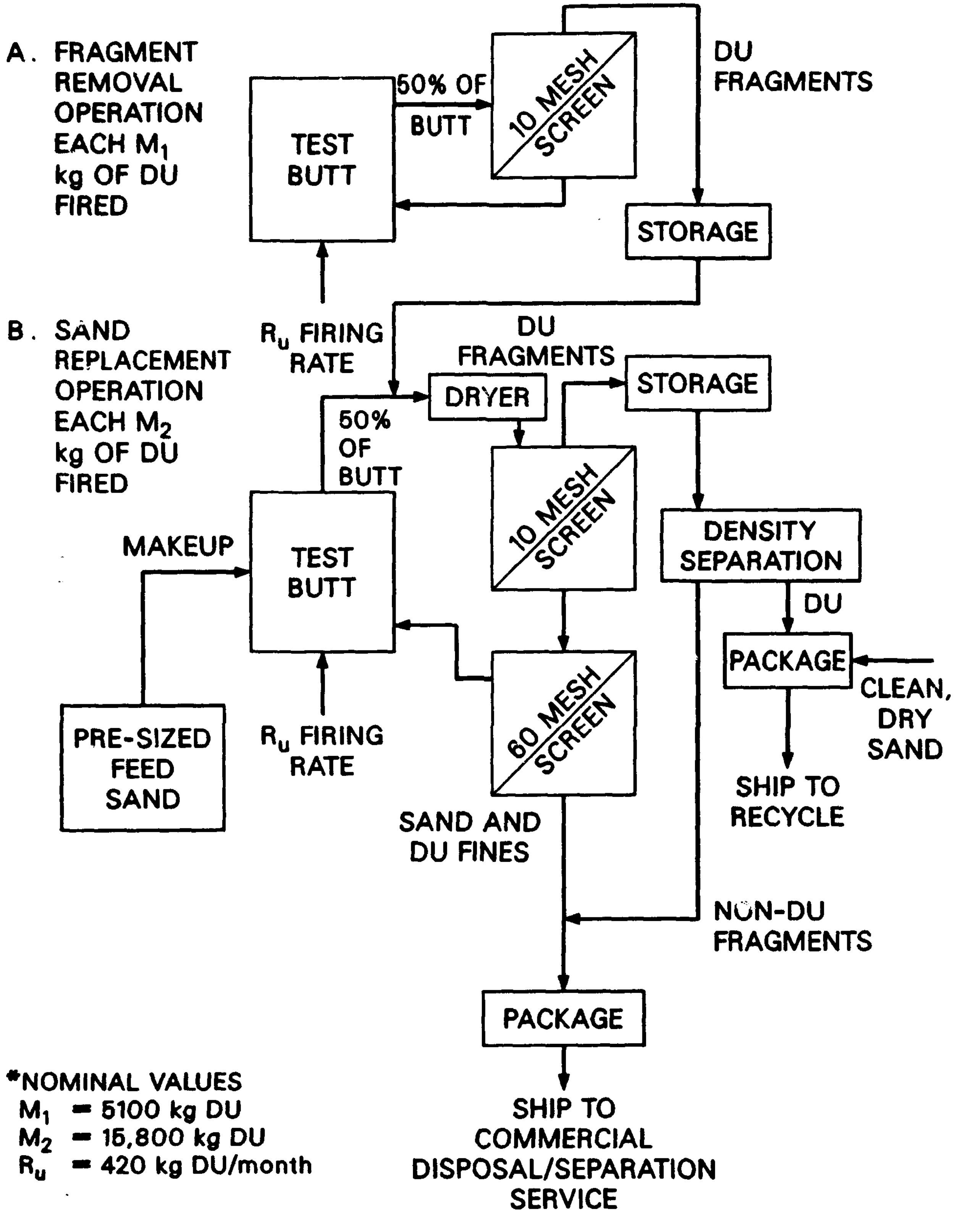

Figure 4. Flow Sheet for Option 2.

pyrophoric," are made inert with fresh, dry sand and packaged in 55-gallon drums, with maximum loose contents of 553 kg (1217 pounds) for shipment to a DU fabricator such as Aerojet-General of Jonesborough, Tennessee. The fines are dried and also packaged in 55-gallon drums, with maximum contents of 553 kg (1217 pounds) ready for shipment to the subcontractor.

TABLE 5. OPERATING COSTS FOR OPTION 2

Cost element	Cost	Reference
Screening ($\$/ft^3$ sand)	1.8	Appendix B
Major cleanup start-up cost ($\$ \times 10^3$)	25	Estimate
Recycle material contract management ($\$ \times 10^3$)	25	Estimate
DU/aluminum fragment separation ($\$/ft^3$ sand)	0.14	
Transportation of DU fragments ($\$/ft^3$ sand)	77	Weight limited
DU sales ($/kg DU)	0	
Drying and packaging ($\$/ft^3$ sand)	22.6	Appendix A
Transportation of sand fines ($\$/ft^3$ sand)	10	Estimate[a]
Contaminated fines acceptance fee ($\$/ft^3$ sand)	125	Estimate[b]

[a]Destination, Nevada — transportation cost within the United States could range from \$5 to $\$25/ft^3$ sand.

[b]Equals 25% of the cost proposed by Ayres for pilot-scale tests, estimated per cubic foot of sand.

5. Shutdown Method

The decommissioning process for Option 2 includes complete removal, drying, and packaging of contaminated sand. The sand is shipped to a contractor and derated using the same process that is used to separate DU from sand fines. The bulk of the sand would meet the requirements for unlimited disposal. A relatively small volume of DU-rich material is sent to a commercial disposal facility. Contaminated processing equipment and other surfaces are cleaned using standard surface washing techniques, as described for Option 0 (Section III.A).

D. OPTION 3 - DERATING FINES USING A SECONDARY WET SEPARATION SYSTEM

1. Flow Sheet

Figure 5 is a flow sheet for screening followed by wet separation (Option 3). The sand is removed from the butt for coarse screening at the same frequency as used in Option 0 (every 17,000 GAU-8 rounds). Coarse screens down to 10-mesh (1700 μm) are used in place of the 1/2-inch screen to increase the amount of DU removed. Instead of replacing all of the sand in the butt after firing 53,000 GAU-8 rounds (15,800 kg DU), the sand is screened to remove both the oversized material and fines, resulting in a mixture of sand and DU particles that meet the criteria for DU catchment media (see Section III.B).

After screening, the intermediate material is returned to the butt. The oversized material is dried and blended with DU-rich fines that are produced by a secondary separation process that removes DU from sand fines.

A mineral jig is assumed to separate the fines into a derated sand stream with an activity <40 pCi/g (≈35 ppm DU on a mass basis) and a DU-rich stream. The technical feasibility of this step is doubtful.[2] The clean sand is disposed of on-site; the DU-rich material is dried, blended with the oversized material, packaged, and sent to a commercial radioactive waste disposal facility.

2. Capital Costs for Wet Separation

The equipment needed for Option 3 includes screening equipment identified in Table 3 and additional wet separation and water treatment equipment shown in Table 6.

3. Operating Costs and Procedures

The operating costs for Option 3 include all of the Option 1 costs plus an additional cost for sand fines processing. The processing costs over and above those for Option 1 are listed in Table 7.

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2 Tests performed under subcontract (Reference 7) indicated poor performance of the mineral jig on fine particles (60-mesh).

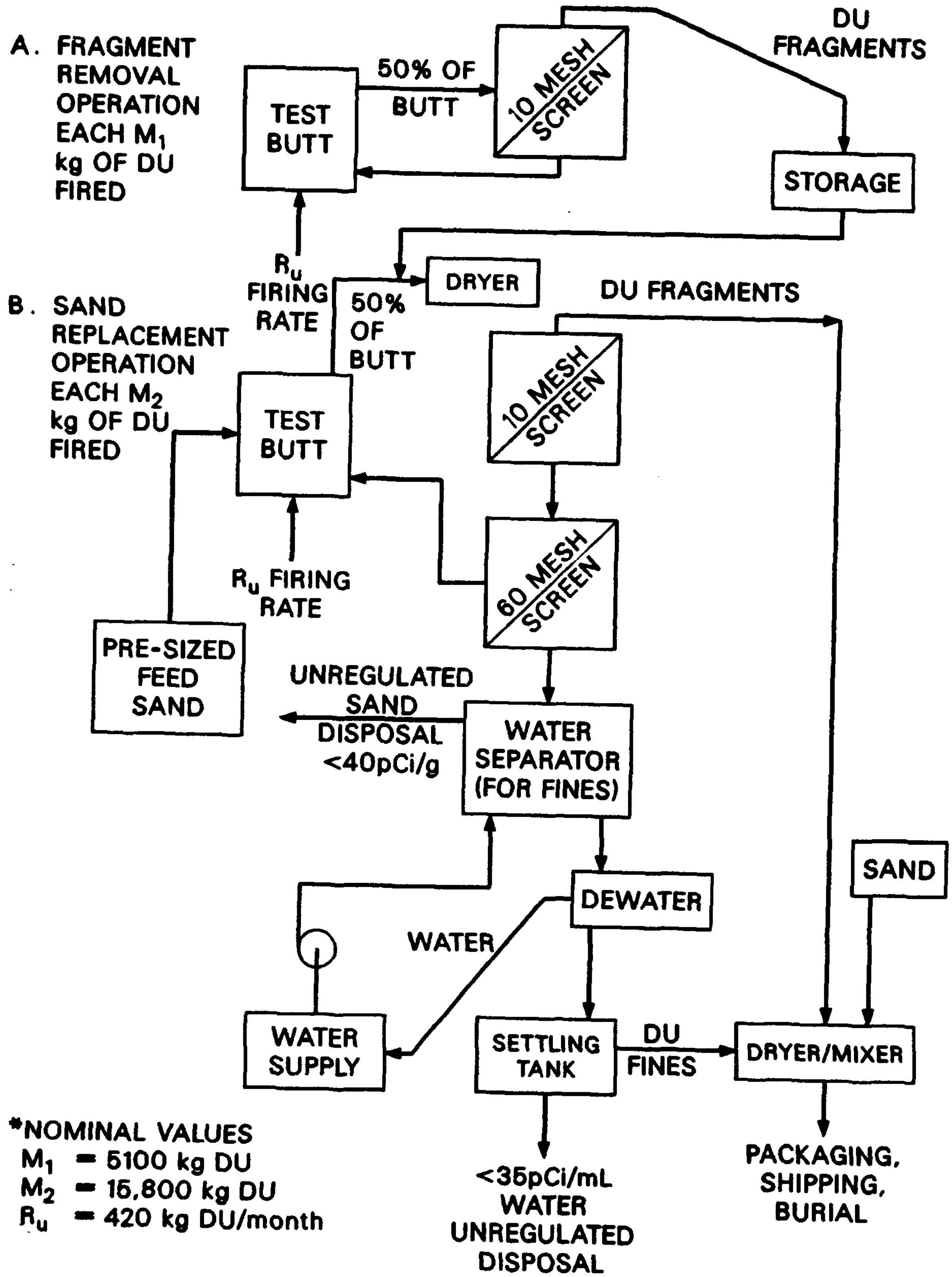

Figure 5. Flow Sheet for Option 3.

TABLE 6. ADDITIONAL CAPITAL COSTS FOR OPTION 3(IN ADDITION TO OPTION 1)

Item	Size	Installed cost ($ X 10^3)
Mineral jig	1 yd^3/h	39
Filter press	10 ft^2	6
Settling tank	1.200 ft^2	10
Concrete pad and pavilion (additional area)	10.000 ft^2	65
Total[a]		120

[a]Includes installation plus 30% contingency.

TABLE 7. ADDITIONAL OPERATIONAL COSTS FOR OPTION 3 (RELATIVE TO OPTION 1)

Cost element	Cost	Reference
Wet separator start-up ($ X 10^3)	20	Estimate
Sand fines processing ($/$ft^3$ sand)	6	Estimate

4. Packaging and Disposal Method

The sand removed from the butt during a replacement operation is separated into three size fractions using conventional screening technology, as for Option 1. The intermediate sizes are recycled to the butt. It is assumed that ~60 percent of the fines are decontaminated by means of the wet separator. The remaining uranium-rich fines are dried, blended with the oversize material, packaged in 55-gallon drums qualified as Type-A containers (per 49 CFR 173.465), and sent to a commercial radioactive waste burial facility.

5. Shutdown Method

The decommissioning process for Option 3 includes complete removal and derating of the contaminated sand. Using the same process used to separate DU from sand fines, the bulk of the sand meets the requirements for unlimited disposal. A relatively small volume of DU-rich material is sent to a commercial disposal facility. Contaminated processing equipment and other surfaces are cleaned using standard surface washing techniques, as described for Option 0 (Section III.A).

E. OPTION 4 - ACID LEACHING OF FINES

1. Flow Sheet

Figure 6 is a flow sheet for screening followed by acid leaching (Option 4). The sand is removed from the butt for coarse screening at the same frequency as used in Option 0 (every 17,000 GAU-8 rounds). Coarse screens down to 10-mesh (1700 mm) are used in place of the 1/2-inch screen to increase the amount of DU removed. Instead of replacing all of the sand in the butt after firing 53,000 GAU-8 rounds (15,800 kg DU), the sand is screened to remove both the oversized material and fines, resulting in a mixture of sand and DU particles that meet the criteria for DU catchment media (see Section III.B).

After screening, the intermediate material is returned to the butt. The oversized material is dried and blended with uranium-rich solids from the acid-leaching process. The DU is removed from the fines using an acid-leaching process that concentrates all of the DU in a very small stream.

An acid-leaching process for derating DU-contaminated sand is described in Reference 6. Three different processes, comparable in complexity, were identified and tested at the bench scale. The process shown in Figure 7 represents Stages A to G in Reference 6. Bench-scale tests indicate that the deregulated sand will contain ~20 ppm DU (mass basis).

2. Capital Costs for Acid Leaching

The equipment needed for Option 4 includes steam-heated stainless steel processing vessels for all of the unit operations shown in Figure 7, pumps, controls, and process piping. A neutralizer, acidic gas scrubber, HEPA filter system, and evaporator would also be required to support the process. Table 8 lists the major capital equipment costs for Option 4.

3. Operating Costs and Procedures

The operating costs for Option 4 include all of the costs included in Option 1 (except burial) plus the start-up and operating cost for the acid-leaching process. The Oak Ridge Y-12 Plant uses an acid-leaching process to recover highly enriched uranium from CaF_2 slag that is almost identical to the one described in Reference 6. The Y-12 process was installed more than 20 years ago and operates on a continuous basis; so its cost is probably well below that of a new process operated on an intermittent basis. The FY 1986 operating cost for the Y-12 process is \$16/kg slag, which translates to \$730/ft^3 sand at a density of 100 lb/ft^3.

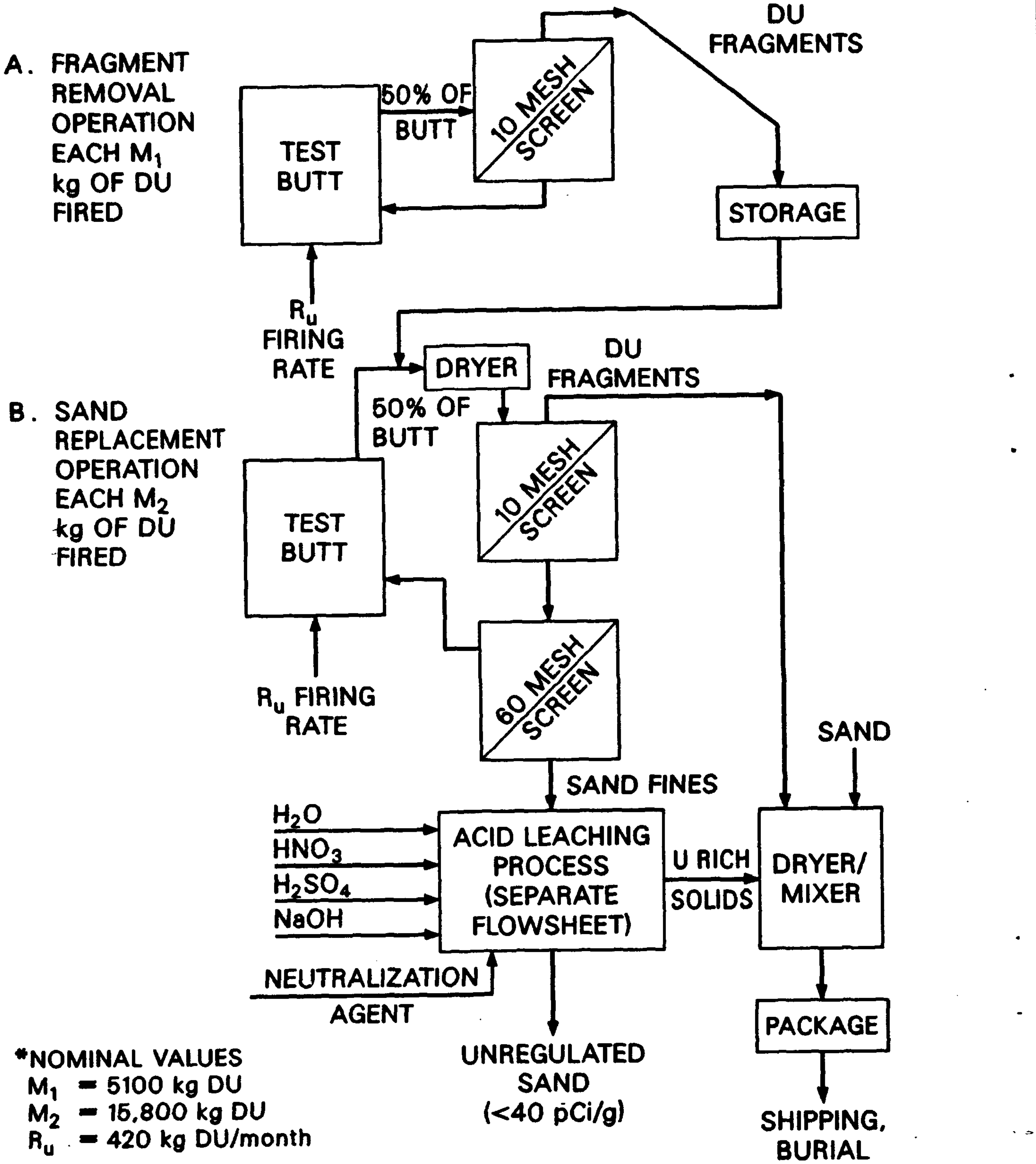

Figure 6. Flow Sheet for Option 4.

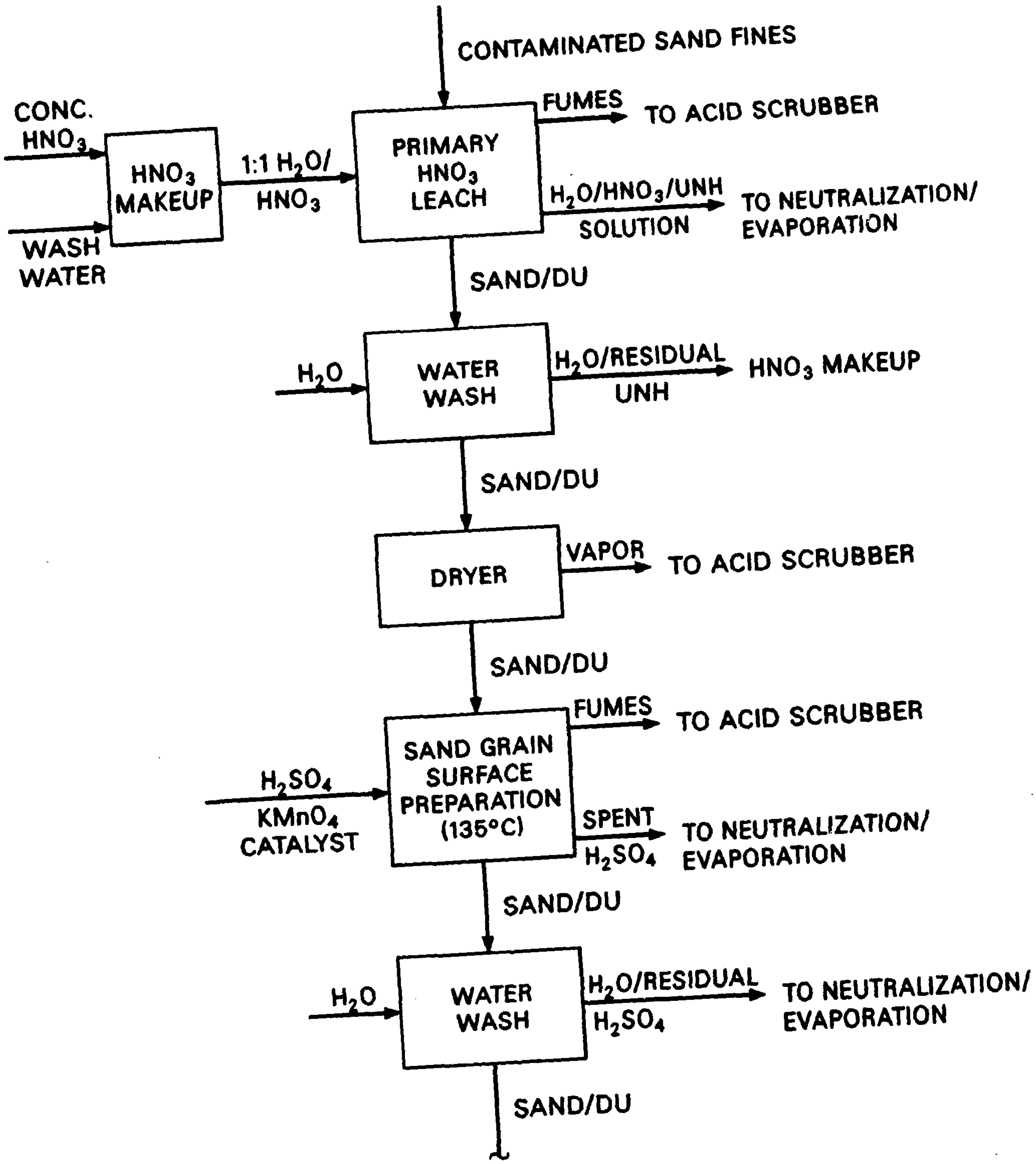

Figure 7. Detailed Flow Sheet for Acid-Leaching Process.

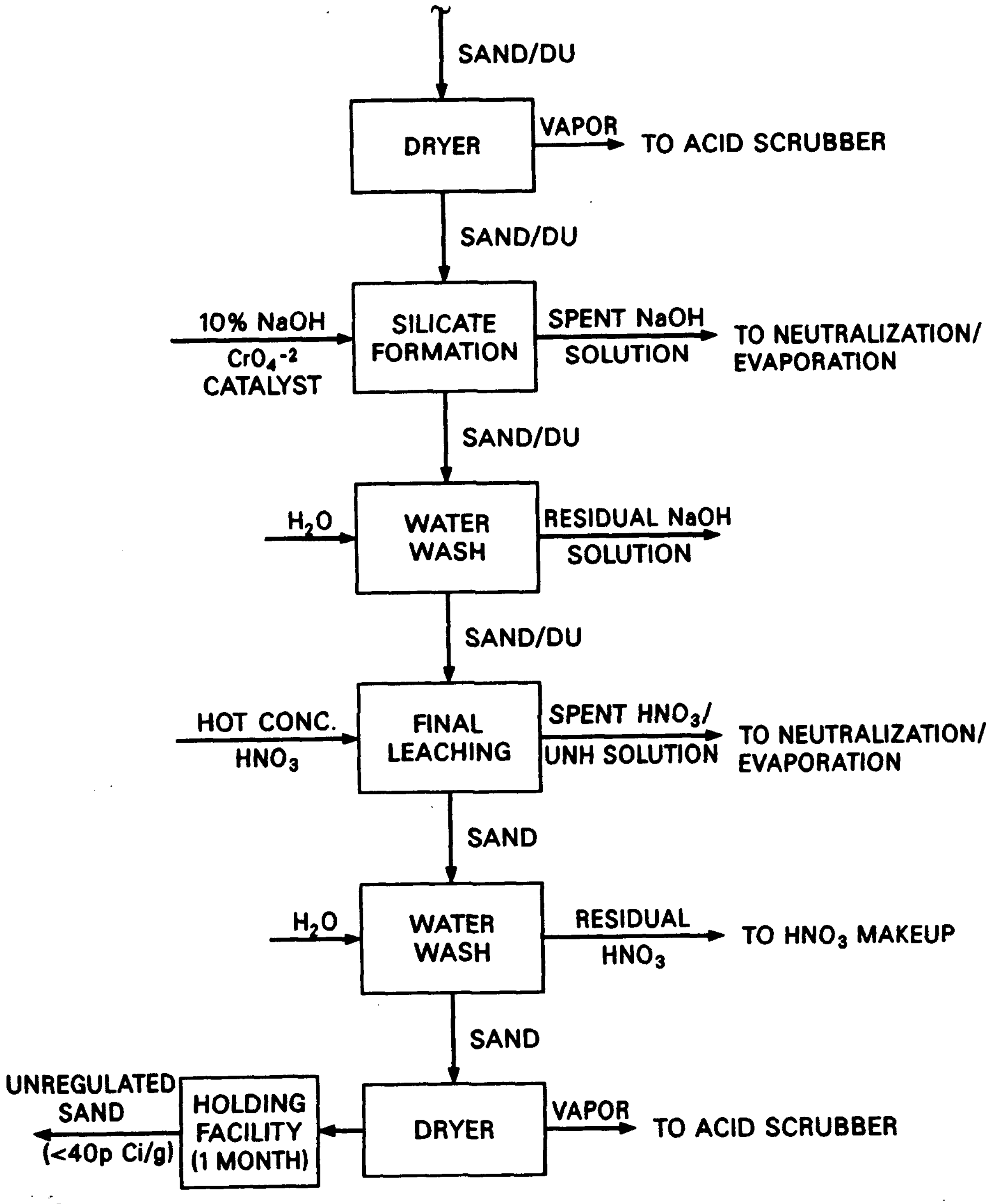

Figure 7. Detailed Flow Sheet for Acid-Leaching Process.
(Continued)

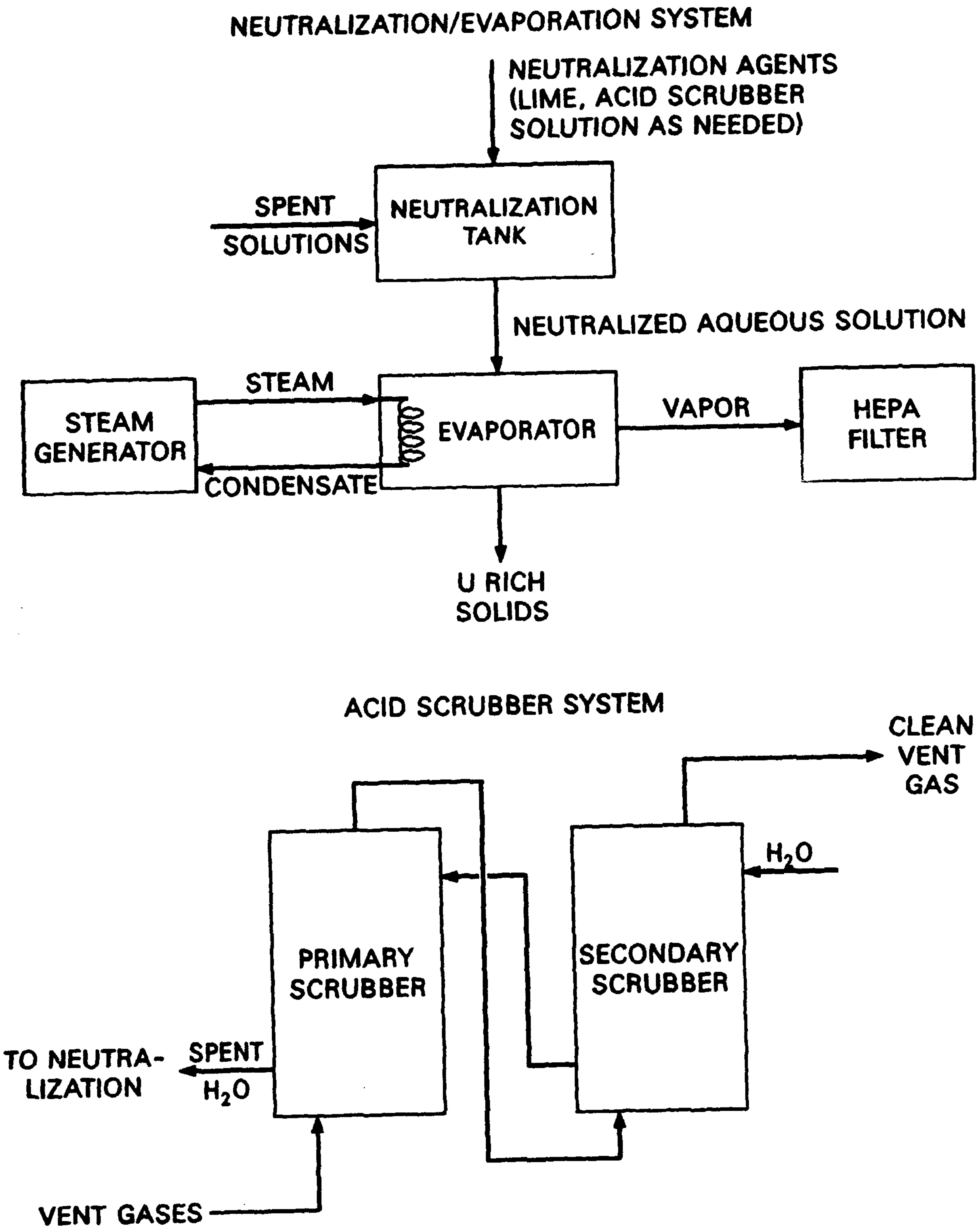

Figure 7. Detailed Flow Sheet for Acid-Leaching Process. (Continued)

TABLE 8. APPROXIMATE ADDITIONAL CAPITAL COSTS FOR OPTION 4 (IN ADDITION TO OPTION 1)

Item	Size	FOB cost ($ X 10^3)
Processing tanks, 10 ea.	800 ft^3	600
Pumps, 10 ea.	7 hp	120
Evaporator system		34
Acid scrubber		60
Total major equipment		814
Total assembled cost[a]		4884
Concrete pad and Pavilion	20,000 ft^2	130
Total capital cost		5014

[a]A ratio of 6.0 for total capital investment/major equipment cost is appropriate for this complete chemical process.

The start-up cost for a complex chemical process is typically 10 percent of fixed capital investment (Reference 5). Assuming that the process could be started up every three years for 20 percent of the first start-up cost, it is:

Capital cost		Start-up ratio		Restart ratio		
$5,000 X 10^3	X	0.10	X	0.20	=	$100 X 10^3.

This estimate is probably too low, but the acid-leaching process is so expensive that its relative cost ranking is not influenced by the start-up cost.

4. Shutdown Method

The decommissioning process for Option 4 includes complete removal of the contaminated sand. The DU would be removed from the sand using the same acid-leaching process used to separate DU from sand fines. Most of the sand would meet the requirements for unlimited disposal. A relatively small volume of uranium-rich solids would be sent to a commercial disposal facility. Contaminated processing equipment and other surfaces would be cleaned using standard surface washing techniques and reclaimed, as described for Option 0 (Section III.A), or dismantled and buried as contaminated waste. The amount and size of chemical process equipment result in a relatively high shutdown cost.

F. MODIFIED TEST BUTT (OPTION 5)

1. Flow Sheet

Figure 8 is a flow sheet for the modified test butt (Option 5). This concept involves minor changes in design and operational procedures to limit the portion of the butt that actually accumulates DU projectiles. This system models the one used by Gencorp-Aerojet Ordnance at their Chino Hills facility near Ontario, California, where they test single GAU-8 rounds at a muzzle velocity of ~1040 m/s (3410 ft/s).

The butt dimensions are ~12 feet X 12 feet at the face and ~10 feet deep, containing about 60 yd^3 of sand. The sand is contained by a front wall with a 6- X 6-foot window covered with plywood. The DU projectiles are fired through the plywood into the butt. Firing through the window and into a vertical side of the sand beneath the surface limits the amount of sand that becomes contaminated with DU. The projectiles are fired normal to the catchment media, limiting ricochets. Furthermore, sand fines produced in stopping the DU projectiles are retained below the surface.

In current practice, the plywood is replaced after ~100 rounds. At the same time, sand that has spilled out on the concrete apron is returned to the butt. Every two weeks, the front wall is removed, and a limited amount of sand (normally 40 to 50 ft^3) *is loaded in a dump truck and taken to the* DU-contaminated material storage site. Aerojet contracts with AWC of Las Vegas, Nevada, yearly to package the contaminated sand and other material in drums and ship it to the commercial radioactive waste repository at Richland, Washington. Aerojet replaces all of the sand in their butt every 4 to 5 years. The replacement operation parallels Option 0 but is significantly less expensive because drying is not necessary owing to the arid southern California climate and the relatively low volume of sand in the butt.

An Eglin AFB implementation of the Aerojet scheme would differ in several ways. Air drying is not feasible at Eglin; therefore, the prepackaging preparation would require a drier, cooler, and baghouse as for Options 1 and 2. The plywood replacement operation would be more time consuming because (1) the seven-barrel gun at Eglin would cause more damage to the window, which would therefore need to be replaced more frequently, and (2) the operation would be more difficult because of the more stringent occupational hazard rules at Eglin. On the positive side, the sand replacement operation, while comparable to that in Option 0, would involve much less sand because the mode of bullet entry into the side of the butt limits the contaminated volume.

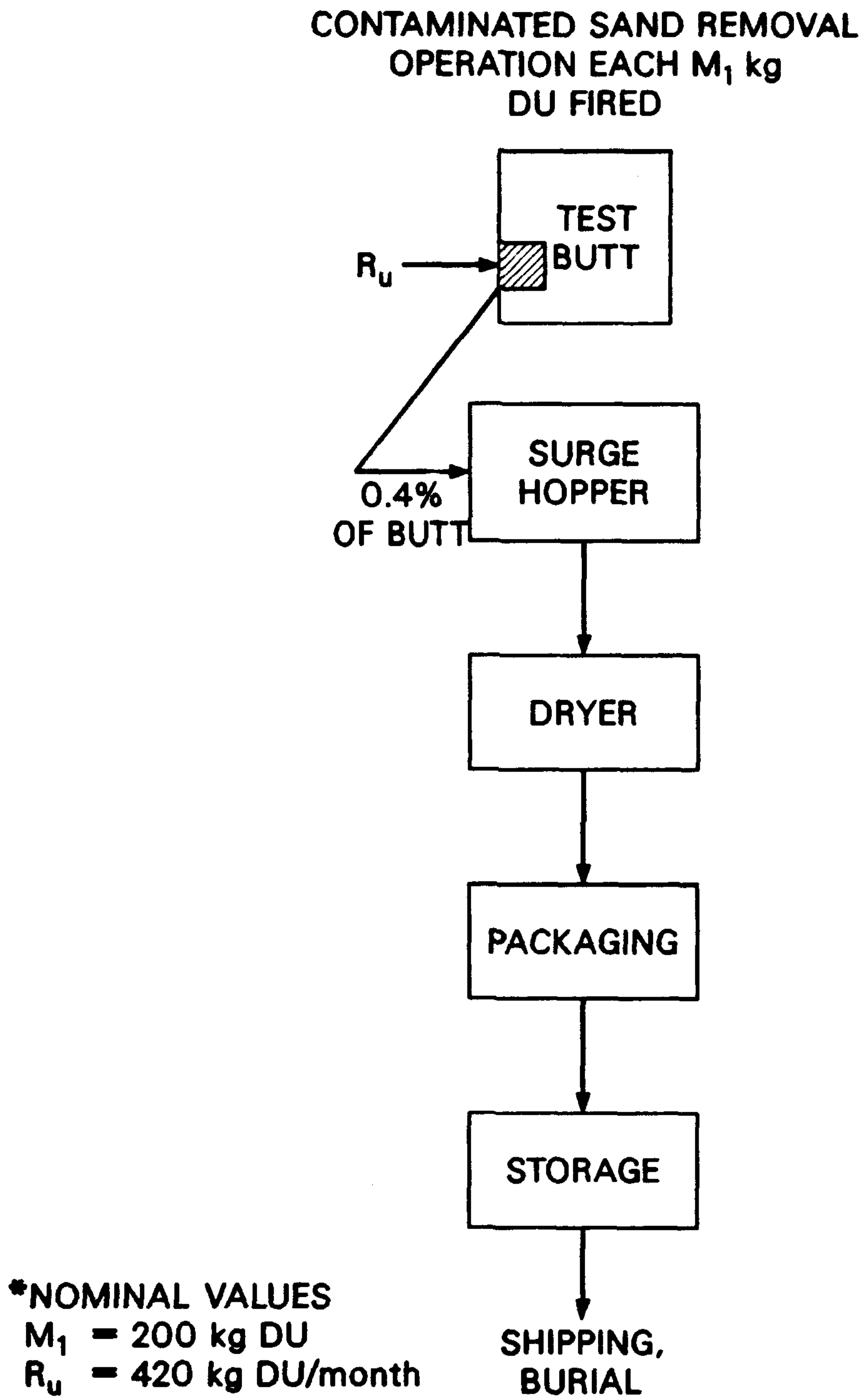

Figure 8. Flow Sheet for Option 5.

2. Capital Costs for Modifying the Test Butt

The capital costs for Option 5 include test butt modification, sand drying and packaging equipment, and a storage facility. Estimates for the major items are included in Table 9.

TABLE 9. MAJOR CAPITAL EXPENSES FOR OPTION 5

Item	Size	Installed cost ($ X 10^3)
Modification to test butt		30
Surge hopper	2 yd^3	21
Transfer conveyor	50 ft	22.5
Dryer	3 million Btu/h	98
Baghouse and fan	15,000 ACFM	38.5
Utilities		10
Concrete pad and pavilion	5,000 ft^2	65
Assembly		93.6
Engineering		37.8
Contingency (20% of equipment, assembly, and engineering)		62.3
Total		478

3. Operating Costs and Procedures

The operating cost elements for Option 5, listed in Table 10, are based on an extrapolation of the Aerojet procedure to conditions at Eglin AFB.

TABLE 10. OPERATING COSTS FOR OPTION 5

Cost element	Cost	Reference
Replacement of plywood face ($)	550	O'Donovan
Removal of contaminated sand ($/month)	3000	Estimate
Drying and packaging ($/$ft^3$ sand)	22.6	Appendix A
Shipping ($/$ft^3$ waste)	4.1	Appendix A
Current burial cost ($/$ft^3$ waste)	37.75	Appendix A
Burial cost escalation (%/year)	6.0	Appendix A

4. Packaging and Disposal Method

The sand removed from the butt during a replacement operation is dried and packaged in 55-gallon drums qualified as Type-A containers (per 49 CFR 173.465) (see Appendix A). The material is stored in the containers until 50 to 100 drums (one to two truckloads) are ready for shipment to a commercial radioactive waste disposal facility.

5. Shutdown Method

The decommissioning process for Option 5 includes complete removal and disposal of contaminated sand. In addition, contaminated surfaces are cleaned using standard surface decontamination techniques for uranium removal (i.e., washing with soap and water). Materials that could not be decontaminated to meet standards in effect at the time and solutions produced in the decontamination process would be packaged and shipped to a commercial radioactive waste disposal facility.

SECTION III
COST MODEL DESCRIPTION AND PARAMETERS COMMON TO ALL OPTIONS

A. SPREADSHEET DESIGN, LOGIC, AND VALIDATION

A computer model using a spreadsheet program has been developed and validated for each option identified in Section III. Costs are summarized by month and by year for the assumed 20-year life of the project. Results are presented as both discounted and undiscounted cash flows. Benefits (i.e., utility derived from having a sand butt) are assumed to be the same for all options; so only costs were considered in the analysis.

1. Spreadsheet Description

The spreadsheets for estimating the cost of each option use the same basic parameters and logic, including a list of input parameters, followed by a summary of costs by element (in discounted and undiscounted dollars) and the actual yearly costs.

2. Spreadsheet Logic

A simplified flowchart showing the logic used in the analysis is given in Figure 9. The sand/DU processing and disposal model is entirely first order. In other words, decisions on when to process sand; the cost of processing, transportation, and disposal; and material balances for DU and sand fines in the butt are based on linear algebraic equations. For example, the amount of sand fines in the butt (in kilograms) is estimated by

$$\text{Sand fines} = c_1 \text{ (total sand)} + c_2 \ (\Sigma \text{ DU fired}),$$

with the following four adjustable parameters:

c_1	=	mass fraction of fines in clean sand,
c_2	=	kilograms of sand fines produced per kilograms DU fired
total sand	=	total sand placed in butt (in kilograms),
Σ DU fired	=	total DU fired into the butt (in kilograms).

The amounts of DU and sand fines in the butt are determined at the end of each month, and a decision is made as to whether to process the sand in the butt. Decisions concerning when to process sand in the butt, the DU firing rate, and most of the cost data are based on historical records.

The only parameters that are not adjustable are physical invariants, conversion factors, and the 20-year life of the project for each option. Although 20 years is somewhat arbitrary, there is no indication that the Eglin AFB DU firing mission will end before that date, the useful life of processing

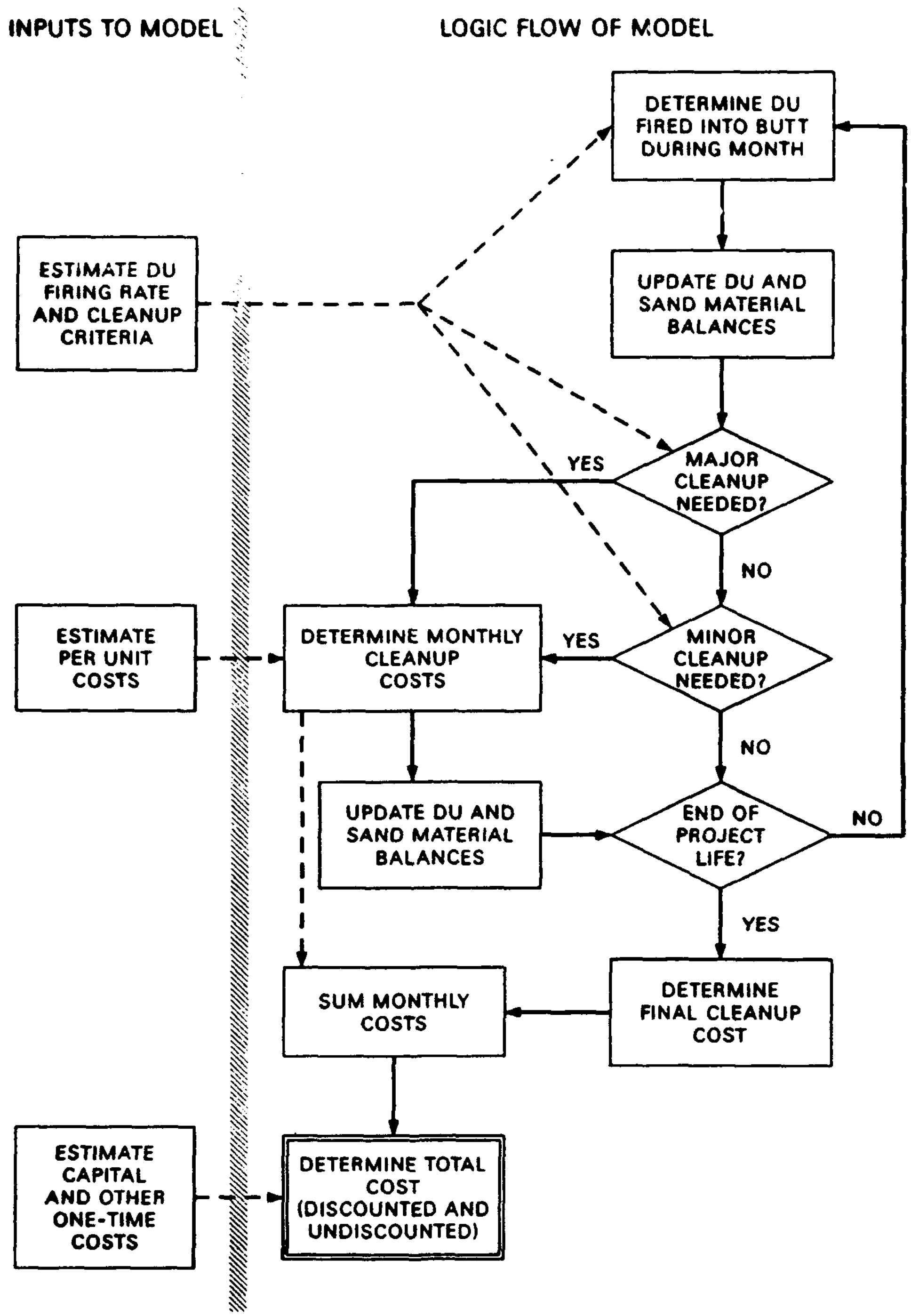

Figure 9. Cost Model Logic Diagram.

equipment is typically between 10 and 30 years, and the 10 percent discount factor substantially negates the effect of costs incurred past 20 years.

3. Validation

The basic steps used in the validation process for the cost model were as follows:

a. Determine that the flow sheets given in Section III accurately represent the processing steps required for each option.

b. Verify that the logic used in each spreadsheet reflects the flow sheets in Section III by examining the formula in each cell (or range of cells).

c. Test the result of each cell or range of cells by comparing the spreadsheet output with hand calculations.

B. DU CATCHMENT PARAMETERS COMMON TO ALL OPTIONS

The cost of each option depends on the DU firing and catchment media parameters listed in Table 11. The amount of sand in the butt, DU firing rate, minor and major cleanout frequencies, ratio of DU fragments to DU fired, and ratio of DU fines (-60-mesh) to DU fired have been extracted from historical records that are summarized in Reference 2.

The screening efficiency for the sand fines (-60-mesh) was determined by Keane in Reference 7. The screening efficiency for DU fines is estimated to be slightly greater than that of sand because screening efficiency should increase at higher density. The extra waste volume accounts for test plates, used HEPA filters, and other nonsand wastes generated during the course of firing and cleanouts.

The amount of fines in the test butt is of interest and depends on the fraction of fines in the makeup sand, the amount of fines produced by DU penetrators as they impact the sand, and the removal rate by the fine screening step. Presized sand that contains only 3 percent fines (-60-mesh) is available in the Eglin AFB area. Options 1 to 5 are designed so that only the fine material will be sent for disposal or otherwise processed in the course of a major cleanout. Minimizing the amount of fines entering the butt with the makeup sand minimizes the processing and disposal costs.

The production of sand fines from DU impact is estimated to be 2.42 kg sand fines produced per kilogram of DU fired. This ratio is based on a comparison of size distributions between used and unused sand. Since the quantity of sand fines is an

important parameter and the data used in determining the sand fines production rate are sketchy, the ratio of sand fines to DU fired has been included in the sensitivity analysis included in Section V.B.

TABLE 11. SAND/DU PROCESSING DATA COMMON TO ALL OPTIONS

Firing rate (kg/month)[a]	417
Sand in test butt (kg)	500,000
DU fired between minor cleanouts (kg)	5,096
DU fired between major cleanouts (kg)	15,800
Fines in sized sand (wt %)	3
Fines from firing (kg sand/kg DU)[a]	2.42
Uranium fragments +10-mesh (%)	76
Uranium fines -60-mesh (%)	10
Uranium fines passing 60-mesh screen (%)	85
60-mesh screen efficiency (%)	83
Extra waste volume (ft^3/major cleanout)	500

[a]Sensitivity parameter; see Section V.B.

C. ECONOMIC PARAMETERS COMMON TO ALL OPTIONS

Economic parameters common to all options are listed in Table 12. The bases for screening, fixation, drying, packaging, shipping, and disposal costs are included in Appendices A and B. The discount rate is specified in AFR 178-1 (Reference 3).

TABLE 12. ECONOMIC DATA COMMON TO ALL OPTIONS

New sand, sized (\$/yd^3 sand)	12.00
Burial cost at Barnwell (\$/ft^3 waste)	37.75
Burial cost at new facility (\$/ft^3 waste)[a]	100.00
Remaining life of Barnwell (years)	4
Escalation factor for burial (%/year)	6.0
Discount rate (%/year)	10.0

[a]Sensitivity parameter; see Section V.B.

TABLE 13. DISCOUNTED LIFE-CYCLE COSTS ($ X 10^6) FOR OPTIONS 0 THROUGH 5

Cost element	Option 0	Option 0′	Option 1	Option 2a	Option 3a	Option 4	Option 5
Screening	0.1	0.1	0.1	0.1	0.1	0.1	NA
Packaging	0.8	0.5	0.1	0.1	0.0	0.0	0.2
Transportation	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Burial	4.2	5.0	1.0	NA	0.5	0.0	1.6
Fines separation	NA[b]	NA	NA	0.5	NA	2.7	NA
Fixed operating costs	0.7	0.1	0.1	0.1	0.2	0.4	0.0
Test butt maintenance	NA	NA	NA	NA	NA	NA	1.0
Capital	NA	0.4	0.6	0.8	0.9	5.6	0.5
Shutdown	0.1	0.1	0.1	0.1	0.1	0.2	0.1
Total cost[c]	5.9	6.3	2.0	1.5	1.7	9.1	3.3

[a]Not technically feasible.
[b]NA — Not applicable for this option.
[c]Totals appear inexact because of roundoff.

SECTION IV
RESULTS AND DISCUSSION

A. ECONOMIC COMPARISON OF OPTIONS 0 TO 5

Life-cycle cost estimates for Options 0 to 5 are presented in this section. Much of the operational cost data were obtained from the actual costs for the 1986-87 contaminated sand disposal effort. When no actual cost data were available, capital and operating costs were estimated using the "study estimate" technique described by Bauman (Reference 8). The accuracy of a study estimate is typically 30 percent.

1. Life-cycle Costs

Discounted life-cycle costs for each option are given in Table 13 and are presented in graphical form in Figure 10.

2. Time Series Analysis of Cash Flows

The annual undiscounted cost for each option is given in Tables 14 to 19. A 20-year life was assumed for each option. The data presented in Tables 14 to 19 show capital cost in year 0, operating costs for years 1 to 20, and shutdown costs in year 21.

B. SENSITIVITY ANALYSIS

1. Disposal Cost

A detailed discussion of the current and future disposal cost for low-level radioactive waste is given in Appendix A. Briefly, the disposal cost has increased 10 percent/year from 1985 to 1989, significantly above the inflation rate. The Southeast Compact's current disposal facility in Barnwell, South Carolina, is scheduled to be closed in 1992 and will be replaced with a significantly more expensive above-ground facility. The current disposal cost estimates for the new facility range from \$80 to \$120/ft^3, which is two to three times the current rate. The post-1992 burial cost used in the tables in Section V.A was \$100/ft^3. The impact of higher burial costs is given in Table 20.

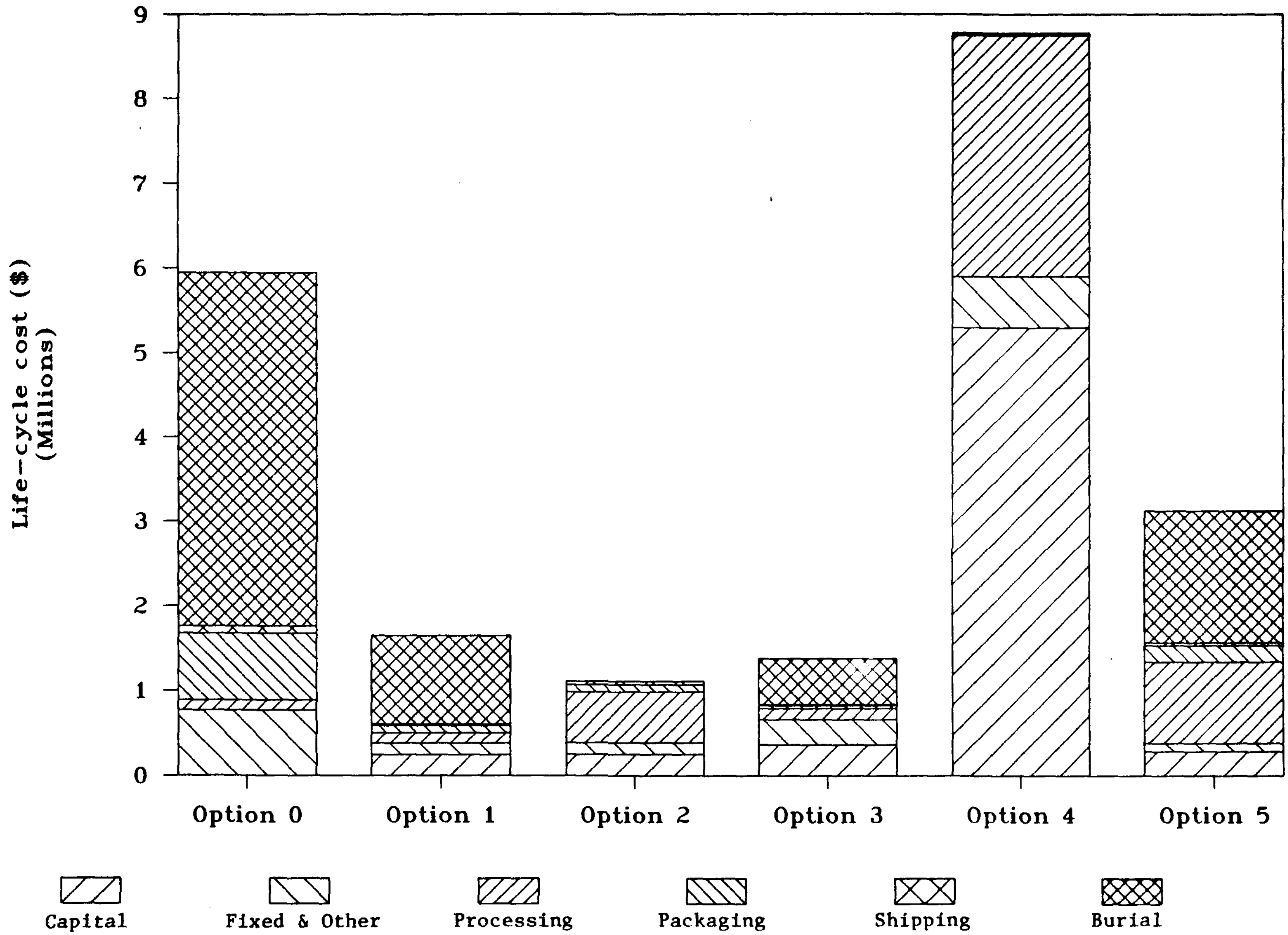

Figure 10. Life-cycle Cost of Sand/DU Processing and Disposal.

TABLE 14. ANNUAL COSTS ($ X 10^3) FOR SAND/DU PROCESSING AND DISPOSAL FOR OPTION 0

YEAR	0	1	2	3	4	5	6	7	8	9	10
Capital cost	0	0	0	0	0	0	0	0	0	0	0
Minor cleanup											
Screening	0	0	13	13	0	13	13	0	13	13	0
Major cleanup											
Fixed cost	0	0	0	0	0	0	0	590	0	0	0
Screening	0	0	0	0	19	0	0	19	0	0	19
Packaging	0	0	0	0	0	0	0	730	0	0	0
Shipping	0	0	0	0	0	0	0	79	0	0	0
Burial (incl. infl.)	0	0	0	0	0	0	0	2800	0	0	0
New sand	0	0	0	0	5	0	0	5	0	0	5
Shutdown cost	0	0	0	0	0	0	0	0	0	0	0
Undiscounted annual cost	0	0	13	13	24	13	13	4223	13	13	24
Discounted annual cost	0	0	11	10	17	9	8	2273	6	6	10

YEAR	11	12	13	14	15	16	17	18	19	20	21
Capital cost	0	0	0	0	0	0	0	0	0	0	0
Minor cleanup											
Screening	13	13	0	13	13	0	13	13	0	0	0
Major cleanup											
Fixed cost	0	0	590	0	0	0	0	0	590	0	390
Screening	0	0	19	0	0	19	0	0	19	0	19
Packaging	0	0	730	0	0	0	0	0	730	0	365
Shipping	0	0	79	0	0	0	0	0	79	0	42
Burial (incl. infla.)	0	0	4050	0	0	0	0	0	5857	0	3274
New sand	0	0	5	0	0	5	0	0	5	0	5
Shutdown cost	0	0	0	0	0	0	0	0	0	0	500
Undiscounted annual cost	13	13	5473	13	13	24	13	13	7281	0	4795
Discounted annual cost	5	4	1663	4	3	5	3	2	1249	0	748

TABLE 15. ANNUAL COSTS ($ X 10^3) FOR SAND/DU PROCESSING AND DISPOSAL FOR OPTION 1

YEAR	0	1	2	3	4	5	6	7	8	9	10
Capital cost	599	0	0	0	0	0	0	0	0	0	0
Minor cleanup											
Screening	0	0	15	15	0	15	15	0	15	15	0
Major cleanup											
Fixed cost	0	0	0	0	25	0	0	25	0	0	25
Screening	0	0	0	0	15	0	0	15	0	0	11
Packaging	0	0	0	0	21	0	0	20	0	0	20
Shipping	0	0	0	0	6	0	0	6	0	0	6
Burial (incl. infla.)	0	0	0	0	65	0	0	205	0	0	245
New sand	0	0	0	0	0	0	0	0	0	0	5
Shutdown cost	0	0	0	0	0	0	0	0	0	0	0
Undiscounted annual cost	599	0	15	15	132	15	15	271	15	15	311
Discounted annual cost	599	0	13	12	95	10	9	146	7	7	126

YEAR	11	12	13	14	15	16	17	18	19	20	21
Capital cost	0	0	0	0	0	0	0	0	0	0	0
Minor cleanup											
Screening	15	15	0	15	15	0	15	15	0	0	0
Major cleanup											
Fixed cost	0	0	25	0	0	25	0	0	25	0	25
Screening	0	0	15	0	0	15	0	0	15	0	15
Packaging	0	0	20	0	0	20	0	0	20	0	249
Shipping	0	0	6	0	0	6	0	0	6	0	47
Burial (incl. infla.)	0	0	294	0	0	353	0	0	424	0	3715
New sand	0	0	0	0	0	0	0	0	0	0	5
Shutdown cost	0	0	0	0	0	0	0	0	0	0	500
Undiscounted annual cost	15	15	360	15	15	24	15	15	490	0	4556
Discounted annual cost	5	5	109	4	4	5	3	3	84	0	710

TABLE 16. ANNUAL COSTS ($ X 10^3) FOR SAND/DU PROCESSING AND DISPOSAL FOR OPTION 2

YEAR	0	1	2	3	4	5	6	7	8	9	10
Capital cost	607	0	0	0	0	0	0	0	0	0	0
Minor cleanup											
Processing	0	0	15	15	0	15	15	0	15	15	0
Major cleanup											
Fixed cost	0	0	0	0	25	0	0	25	0	0	25
Transportation	0	0	0	0	11	0	0	11	0	0	11
Processing	0	0	0	0	153	0	0	149	0	0	148
New sand	0	0	0	0	0	0	0	0	0	0	0
Credit for DU fragments	0	0	0	0	0	0	0	0	0	0	0
Shutdown cost	0	0	0	0	0	0	0	0	0	0	0
Undiscounted annual cost	607	0	15	15	189	15	15	185	15	15	184
Discounted annual cost	607	0	13	12	135	10	9	100	7	7	74

YEAR	11	12	13	14	15	16	17	18	19	20	21
Capital cost	0	0	0	0	0	0	0	0	0	0	0
Minor cleanup											
Processing	15	15	0	15	15	0	15	15	99	0	0
Major cleanup											
Fixed cost	0	0	25	0	0	25	0	0	25	0	25
Transportation	0	0	11	0	0	10	0	0	10	0	111
Processing	0	0	148	0	0	148	0	0	147	0	
1666											
New sand	0	0	0	0	0	4	0	0	0	0	0
Credit for DU fragments	0	0	0	0	0	0	0	0	0	0	0
Shutdown cost	0	0	0	0	0	0	0	0	0	0	0
Undiscounted annual cost	15	15	185	15	15	24	15	15	183	0	2302
Discounted annual cost	5	5	56	4	4	5	3	3	31	0	359

TABLE 17. ANNUAL COSTS ($ X 10^3) FOR SAND/DU PROCESSING AND DISPOSAL FOR OPTION 3

YEAR	0	1	2	3	4	5	6	7	8	9	10
Capital cost	719	0	0	0	0	0	0	0	0	0	0
Minor cleanup											
Processing	0	0	15	15	0	15	15	0	15	15	0
Major cleanup											
Fixed cost	0	0	0	0	70	0	0	70	0	0	70
Processing	0	0	0	0	20	0	0	20	0	0	20
Packaging	0	0	0	0	8	0	0	8	0	0	8
Shipping	0	0	0	0	4	0	0	4	0	0	4
Burial											
(incl. infla)	0	0	0	0	40	0	0	127	0	0	152
New Sand											
Shutdown cost	0	0	0	0	0	0	0	0	0	0	0
Undiscounted											
annual cost	719	0	15	15	143	15	15	229	15	15	254
Discounted											
annual cost	719	0	13	12	102	10	9	123	7	7	103

YEAR	11	12	13	14	15	16	17	18	19	20	21
Capital cost	0	0	0	0	0	0	0	0	0	0	0
Minor cleanup											
Processing	15	15	0	15	15	15	15	15	0	0	0
Major cleanup											
Fixed cost	0	0	70	0	0	70	0	0	70	0	70
Processing	0	0	20	0	0	20	0	0	20	0	20
Packaging	0	0	8	0	0	8	0	0	8	0	99
Shipping	0	0	4	0	0	4	0	0	4	0	20
Burial											
(incl. infla)	0	0	183	0	0	220	0	0	264	0	1581
New Sand	0	0	0	0	0	0	0	0	0	0	800
Shutdown cost	0	0	0	0	0	0	0	0	0	0	800
Undiscounted											
annual cost	15	15	285	15	15	322	15	15	366	0	2591
Discounted											
annual cost	5	5	87	4	4	73	9	3	63	0	404

TABLE 18. ANNUAL COSTS ($ X 10^3) FOR SAND/DU PROCESSING AND DISPOSAL FOR OPTION 4

YEAR	0	1	2	3	4	5	6	7	8	9	10
Capital cost	5600	0	0	0	0	0	0	0	0	0	0
Minor cleanup Processing	0	0	15	15	0	15	15	0	15	15	0
Major cleanup Fixed cost	0	0	0	0	150	0	0	150	0	0	150
Processing	0	0	0	0	680	0	0	664	0	0	658
Packaging, shipping burial	0	0	0	0	3	0	0	8	0	0	10
New sand	0	0	0	0	0	0	0	0	0	0	0
Shutdown cost	0	0	0	0	0	0	0	0	0	0	0
Undiscounted annual cost	5600	0	15	15	833	15	15	823	15	15	818
Discounted annual cost	5600	0	13	12	597	10	9	443	7	7	331

YEAR	11	12	13	14	15	16	17	18	19	20	21
Capital cost	0	0	0	0	0	0	0	0	0	0	0
Minor cleanup Processing	15	15	0	15	15	0	15	15	0	0	0
Major cleanup Fixed cost	0	0	150	0	0	150	0	0	150	0	150
Processing	0	0	656	0	0	656	0	0	655	0	8045
Packaging, shipping burial	0	0	11	0	0	13	0	0	16	0	35
New sand	0	0	0	0	0	1	0	0	0	0	5
Shutdown cost	0	0	0	0	0	0	0	0	0	0	1500
Undiscounted annual cost	15	15	818	15	15	819	15	15	821	0	9735
Discounted annual cost	5	5	248	4	4	187	3	3	141	0	1518

TABLE 19. ANNUAL COSTS ($ X 10^3) FOR SAND/DU PROCESSING AND DISPOSAL FOR OPTION 5

YEAR	0	1	2	3	4	5	6	7	8	9	10
Capital cost	0	0	0	0	0	0	0	0	0	0	0
Minor cleanup											
Screening	478	108	108	108	99	108	108	99	108	108	99
Major cleanup											
Fixed cost	0	0	0	0	10	0	0	10	0	0	10
Screening	0	0	0	0	6	0	0	6	0	0	6
Packaging	0	0	0	0	65	0	0	65	0	0	65
Shipping	0	0	0	0	12	0	0	12	0	0	12
Burial (incl infla.)	0	0	0	0	130	0	0	413	0	0	497
New sand	0	0	0	0	1	0	0	1	0	0	1
Shutdown cost	0	0	0	0	0	0	0	0	0	0	0
Undiscounted annual cost	478	0	108	108	323	108	108	605	108	108	689
Discounted annual cost	478	0	103	94	230	85	64	326	53	48	279

YEAR	11	12	13	14	15	16	17	18	19	20	21
Capital cost	0	0	0	0	0	0	0	0	0	0	0
Minor cleanup											
Screening	108	108	99	108	108	99	108	108	99	108	0
Major cleanup											
Fixed cost	0	0	10	0	0	10	0	0	10	0	10
Screening	0	0	6	0	0	6	0	0	6	0	23
Packaging	0	0	65	0	0	65	0	0	65	0	263
Shipping	0	0	12	0	0	12	0	0	12	0	48
Burial (incl infla.)	0	0	598	0	0	719	0	0	865	0	3750
New sand	0	0	1	0	0	1	0	0	1	0	0
Shutdown cost	0	0	0	0	0	0	0	0	0	0	500
Undiscounted annual cost	108	108	790	108	108	911	108	108	1056	108	4594
Discounted annual cost	40	36	240	30	27	208	23	20	181	17	716

TABLE 20. DISCOUNTED LIFE-CYCLE COSTS AS A FUNCTION OF DU FIRING RATE

	Burial Cost ($ X 10^6) at			Total Life-Cycle Cost ($ X 10^6)		
	$100/ft^3 [a]	200/ft^3	400/ft^3	$100/ft^3 [a]	200/ft^3	400/ft^3
Option 0 - Current operation	4.2	8.4	16.7	5.9	10.1	18.5
Option 1 - Improved screening	1.0	2.0	4.0	2.0	3.0	5.0
Option 2[b,c] - DU recycle and private contractor	0.6	1.1	2.0	1.5	1.9	2.9
Option 3[c] - Wet separator	0.5	1.1	2.1	1.7	2.2	3.3
Option 4 - Acid leaching	0.0	0.0	0.1	9.1	9.1	9.1
Option 5 - Modified test butt	1.6	3.0	5.9	3.3	4.8	7.7

[a] Bare case.
[b] Data shown are for an assured processing cost escalation of $125/ft^3, $250/ft^3, and $500/ft^3.
[c] Options 2 and 3 are not technically feasible.

Increases in disposal costs significantly increase the life-cycle cost of Options 0 and 5 because of the large burial volumes required for these options.
Option 4 (acid leaching) is not sensitive to burial cost because only a small quantity of waste is generated. (However, the cost of Option 4 remains high compared to other alternatives.)

Options 2 and 3 are relatively insensitive to disposal cost, but neither option is technically completely feasible. The life-cycle cost of Option 1 (improved screening) increases by ~\$10,000 with each $\$1/ft^3$ increase in disposal cost. Option 1 is consistently less expensive than Options 0, 4, and 5 (the other feasible options) over the range of disposal costs for the above-ground repository of $\$100/ft^3$ to $\$400/ft^3$.

2. DU Firing Rate

Between January 1979 and June 1988, the firing rate averaged 417 kg DU/month with a standard deviation of 760 kg DU. The impact of higher and lower DU firing rates is given in Table 21. The absolute cost of each option changes with the firing rate, but the relative costs remain constant.

3. Sand Fines Production Rate

Prefiring and postfiring size distribution data indicate that the ratio of sand fines (-60-mesh) produced to DU fired is ~2.4 on a mass basis. However, this number is not well defined. This ratio impacts the cost of Options 1 to 4 since only the sand fines are processed or sent for disposal in these cases. It has minimal impact on Options 0 and 5. The life-cycle cost of each option at 1.0, 2.4, and 5.0 kg sand fines per kilogram of DU fired is given in Table 22. As the ratio of sand fines to DU fired increases, the cost advantage of removing the oversized and undersized material and returning the intermediate fraction to the butt decreases.

C. NONECONOMIC COMPARISON OF OPTIONS 0 TO 5

Noneconomic factors that must be considered in selecting a disposal option include technical feasibility, safety and environmental concerns, and process considerations. Table 23 summarizes the noneconomic factors.

TABLE 21. DISCOUNTED LIFE-CYCLE COSTS AS A FUNCTION OF DU FIRING RATE

	Life-cycle cost ($ X 10^6) at a firing rate of 210 kg/month	420 kg/month[a]	340 kg/month
Option 0 - Current operation	2.9	5.9	11.1
Option 1 - Improved screening	1.7	2.0	2.8
Option 2[b] - DU recycle and fines separation	1.2	1.5	2.1
Option 3[b] - Wet separation	2.9	5.9	11.1
Option 4 - Acid separation	1.7	2.0	2.8
Option 5 - Modified test butt	1.2	1.5	2.1

[a]Base case.
[b]Not technically feasible.

TABLE 22. DISCOUNTED LIFE-CYCLE COSTS AS A FUNCTION OF SAND FINES PRODUCTION

	Life-cycle cost ($\$ \times 10^6$) at a sand fine production ratio (kg fines/kg DU fired) of		
	1.0	2.4[a]	5.0
Option 0 - Current operation	5.9	5.9	5.9
Option 1 - Improved screening	1.8	2.0	2.4
Option 2[b] - DU recycle and private contractor	1.3	1.5	1.8
Option 3[b] - Wet separation	1.6	1.7	1.9
Option 4 - Acid separation	8.3	9.1	10.6
Option 5 - Modified test butt	3.3	3.3	3.3

[a]Base case.
[b]Not technically feasible.

TABLE 23. SUMMARY OF NONECONOMIC CONSIDERATIONS

	Technical risk	Safety and environ. risk	Complexity	Process considerations	
				Proprietary	Flexibility
0 Current operation	None	Low	Low	No	High
1 Improved screening	Low	Low	Low	No	Moderate
2 Contractor processing	Moderate	Unknown	Low	Yes	Unknown
3 Wet separation (derating)	High	Moderate	Moderate	No	Low
4 Acid leaching	Moderate	High	Very High	No	Moderate
5 Modified test butt	Low	Low	Low	No	Moderate

1. Technical Feasibility

Technical feasibility can be viewed as the risk that the process will not be workable as designed. There is no technical risk for Option 0 (current operation); it has worked in the past, and there is no reason to believe that it will not be adequate in the future.

Options 1 and 5 are low-risk processes. The principal unknown factor for Option 1 (improved screening) is the impact that a buildup of intermediate-sized DU particles will have on operations. It does not violate any of the identified criteria, but there is no experience with a test butt containing 2 to 3 percent DU (by mass). Option 5 (modified test butt) is low risk because it is currently being used by Gencorp-Aerojet Ordnance.

Option 4 (acid leaching) is a moderate to high risk alternative. It involves a complex acid-leaching process that has been demonstrated on the bench scale. However, very similar processes are used by Department of Energy (DOE) contractors to recover weapons-grade uranium from various slag materials; so the technology is not unknown. The principal technical risk for Option 4 is that intermittent operation of a complex chemical process that uses strong oxidizing agents can result in equipment corrosion and other failures of process equipment.

Options 2 and 3 are high risk. Option 2 (contractor processing) depends entirely on claims made by AWC, Inc., that have not been substantiated with test data. Option 3 (wet separation) requires that the sand fines be "derated" with a wet separation process. Three independent attempts to separate DU from sand to the degree necessary (~35 ppm DU) have been unsuccessful (References 1, 7, and 9).

2. Onsite Safety and Environmental Considerations

The probability of exposing workers to hazardous materials and releasing those materials from the site should be minimized. Another objective is to minimize the chance of producing a secondary radioactive waste stream in the process of separating DU from sand.

Options 0, 1, and 5 involve unit operations that have been proven to be safe at Eglin AFB with adequate health physics control. However, Option 5 requires weekly test butt maintenance, resulting in some increased risk to on-site workers.

Not enough data are available on Option 2 (contractor disposal) to adequately address safety and environmental impacts. If the sand/DU separation was performed by a contractor off-site, the on-site safety and environmental impacts would be similar to those of Option 1.

Option 3 (wet separation) can produce a secondary aqueous radioactive waste stream (Reference 1). In any event, DU fines will be suspended in water, resulting in the opportunity for soil contamination if a tank or process line fails.

Option 4 has the greatest potential for safety and environmental problems. The process is designed to dissolve DU, leaving radioactive aqueous solutions that must be treated. Intermittent use of process equipment containing strong oxidizing agents such as nitric and sulfuric acid and aqueous solutions of soluble uranium is very risky. Leaks will occur; the unknown factor is the degree to which the leaking solutions could be contained and treated. A secondary concern is that many of the reactants used in the acid leaching process are strong oxidants, which can injure workers who are accidentally exposed.

3. Process Considerations

Complexity, availability, and flexibility have been identified as process considerations. The disposal process needs to be simple so that it can be started up and operated easily. The availability of technical support is also a consideration. Proprietary processes leave the Air Force dependent on a single vendor. The process should also be flexible. It is virtually certain that regulatory and other changes over the next 20 years will impact the disposal process.

Options 0, 1, and 5 are simple, nonproprietary, and flexible. For example, they would not be impacted by a change in the amount of DU that is allowed in "derated" sand. The screening operations in Option 1 are an extension of the technology currently employed in minor cleanouts. All of the equipment is available from a number of potential vendors.

Option 2 (contractor processing) is simple. However, AWC, Inc., claims that their TRUclean process is unique, which would leave the Air Force dependent on a single vendor.

Options 3 and 4 are complex chemical/physical processes. All of the unit operations are nonproprietary. Option 3 (wet separation) is less flexible than Option 4 (acid leaching) because of the limitations on how much DU can be removed from contaminated sand using a wet separator.

D. DISCUSSION

With the exception of Option 4 (acid leaching), all of the sand processing and disposal processes considered are economically superior to the current operation. Of the remaining four processes, Options 2 and 3 are not completely feasible, as described in Section III.

The economic and noneconomic considerations have been combined in the ranking matrix given in Table 24. The noneconomic ranking categories are technical feasibility, safety, and environmental risk, and processing considerations such as flexibility, simplicity, and availability. The economic categories are life-cycle cost and cost sensitivity. Weighting factors have been assigned to each ranking category according to its relative importance. It is paramount that the process be technically feasible and safe. Process considerations and projected life-cycle cost are somewhat less important because they can be accommodated with operational changes and additional funding. Cost sensitivity is not weighted heavily because no specific scenarios have been identified which would increase costs relative to other technologies. Each weighting factor is multiplied by each ranking, and the resulting five numbers are multiplied together to give an overall score. The results for each category are multiplied rather than added to emphasize the necessity of being ranked middle to high in each, rather than very high in some and low in others.

Option 1 scores high in each category and has the highest overall score. Options 5 and 0 are a distant second and third. The remaining options are rated very low.

Option 1 provides the basis for building an optimal process. For example, if the Air Force decides that DU fragments should be recycled (even at an economic loss), fragment recycle can easily be accommodated. If the amount of sand or DU is excessive in a particular size fraction, the screening operation can easily be modified for additional removal of a given size range. If the Air Force decides to modify the test butt to conform to the Gencorp-Aerojet General configuration, that can also be accommodated. In summary, a process based on double screening is a low-risk, cost-effective, and flexible approach that will meet Air Force needs now and for the next 20 years.

TABLE 24. COMBINED OPTION RANKING MATRIX

	Technical risk	Health, safety, and environment	Processing considerations	Life cycle costs	Cost sensitivity	Score (arithmetic)	Score (geometric)
Weighting Factor	1.0	1.0	0.5	0.5	0.1		
Option							
0	10	8	10	3	3	24.8	180
1	9	8	9	8	7	26.2	907.2
2	1	7	9	10	7	18.2	110.3
3	1	3	5	9	7	11.7	23.6
4	6	1	1	2	10	9.5	3.0
5	9	5	10	5	5	22.0	281.3

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APPENDIX A
DISPOSAL COST BASES

A. PACKAGING REQUIREMENTS

Since packaging and burial form a significant portion of total disposal cost, an effort was made to select the lowest cost packaging method consistent with regulations and practice. The relevant DOT regulations contained in 49 CFR 172 and 49 CFR 173 were examined and are summarized below. In addition, aid in the interpretation of these regulations was sought from experts in the field, including:

Al Porell, Oak Ridge National Laboratory (ORNL), Manager of the DU/sand disposal operation at Eglin AFB in 1986.

Roger Johnson, Chem-Nuclear Systems, Inc., Columbia, South Carolina, director in the 1986 cleanup operation.

Virgil Autrey, Department of Health and Environmental Control, State of South Carolina, Columbia, South Carolina.

Howard Hendershott and Les Cole, Aerojet-General, Jonesborough, Tennessee.

Lisa Stettar, Tennessee Division of Radiological Health, Nashville, Tennessee.

1. Metallic DU Waste

Waste material consisting of metallic DU is categorized as a "radioactive and flammable solid" by 49 CFR 172.101. As such, packaging specifications described in 49 CFR 173.418 are required. This paragraph (49 CFR 173.418) lists the following packaging requirements for metallic DU waste:

a. No more than quantity A_2 (Ci) may be contained in any one package. However, paragraph 173.433 and Table 173.435 specify A_2 as being unlimited for DU.

b. A Type-A package must be used; it must be constructed of materials that are stable with respect to the contents. Stainless steel drums, used in the 1986 disposal effort, meet this qualification. The Type-A package is defined as meeting specifications described in paragraph 173.465 (see Section A.2).

c. The material must be solid and nonfissile.

d. The container must be sealed with positive closures.

e. The material must be free of water and other contaminants that would increase reactivity.

f. The material must be rendered inert by <u>either</u> (1) "mixing with large volumes of inerting materials such as graphite or dry sand, or other suitable inerting materials, or blended into a matrix of hardened concrete; or (2) by filling the innermost container with an inert gas."

2. Class A Container Defined

General requirements are specified in paragraphs 173.24 and 173.412. In addition, a Type-A package must pass the tests prescribed in paragraph 173.465, which states that

a. One prototype package may be used for testing purposes provided the package passes the "water spray test."

b. Water Spray Test. A detailed test is described which a sealed, stainless steel drum will obviously pass.

c. Free Drop Test
(1) The package must be dropped so as to cause maximum damage.
(2) For packages weighing less than 11,000 pounds, a drop height of 4 ft is specified.

d. Compression Test. The container must survive
(1) a weight of five times the contents or
(2) a pressure of 265 lb/ft^2, for a 24-h period.

e. Penetration Test

f. Reduced Atmosphere Test
As stated in part (b) of paragraph 173.418, the type A package of pyrophoric contents must survive the above tests "without leakage of contents."

3. Packaging Other Forms of DU
Paragraph 172.101 recognizes two other forms of DU besides metallic wastes:

a. Radioactive Materials Manufactured from DU (ID No. UN2909). The fabricated bullets, which fall into this category, are packaged under the less restrictive guides described in paragraph 173.421-1, which is stated to apply. Items fabricated from DU are not deemed pyrophoric in this category and may be shipped without inerting. In addition, the test requirements for a Type-A container, defined in paragraph 173.465, do not apply. It is under these less restrictive guidelines that the bullets are shipped from the fabricator to the various users. In addition, the state of Tennessee allows the interpretation that

bullet fragments fall into this category as well. Thus the bullet manufacturer (Aerojet-General, Jonesborough, Tennessee) has received rejected bullet fragments for recycle that are packaged as category UN2909 material.[3]

b. Low-Specific-Activity (LSA) Radioactive Material (Category No. UN2912). Small DU fragments, such as machine turnings or granular pieces (less than about 40-mesh) are often deliberately oxidized to remove them from the pyrophoric category. Paragraph 172.101 refers the packaging of such materials to paragraph 173.425, which specifically includes oxidized DU. This paragraph (173.425) cites packaging requirements for UN2912 (nonpyrophoric, LSA) as being given in paragraph 178.350. Evidently, these materials must be shipped in Type-A containers (following paragraph 173.403 and the tests in paragraph 173.465), however, without inerting.

4. Performed Tests on 55-gallon Drums Containing Sand

The tests prescribed in paragraph 173.465 for Type-A containers were performed on prototype 55-gallon drums containing wet sand.[4] The tests were conducted by the Florida Drum Company in conjunction with the major packaging and disposal operation at Eglin AFB. The tests were performed for Chem-Nuclear Systems, Inc. (CNSI), the contractor for the 1986-1987 disposal operation.

5. Conclusions Regarding Packaging Requirements

a. Solidification of the DU fragment and DU/sand waste in concrete is a possible option, but it is not a necessary approach. A lower-cost and completely acceptable alternate packaging method consists of

(1) Inerting with a suitable amount of dry sand (per paragraph 173.465).

(2) Testing a prototype container for failure as described in paragraph 173.465, as required for packaging a "radioactive and flammable solid."

b. Since the prescribed tests have been performed, the above alternative is a proven satisfactory packaging procedure for loose contents weighing at least 553 kg (1217

3 L. Cole, Aerojet-General, Inc., personal communication to W. M. Bradshaw, Martin Marietta Energy Systems, Inc., February 21, 1989.

4 C. McGovern, letter to C. Hathoway, Chem-Nuclear Systems, Inc., on subject "Florida Drum Company Certification," 611-0002-87 (Chem-Nuclear Systems file No.), January 6, 1987.

pounds). Therefore, this alternative (to solidification in concrete) is selected as the packaging method in view of its significantly lower cost.

c. The regulations do not limit the quantity of DU per package by total curie level (see paragraph 173.433). Limitations on DU content per package are set by

(1) The requirement to inert by addition of a suitable amount of dry sand (paragraph 173.465).

(2) The survival requirement for the Type-A package without breakage or dispersal of contents with respect to tests described in paragraph 173.465.

d. It is judged that the inerting requirement is fulfilled by adopting a maximum DU concentration in dry sand of 10 vol percent. Therefore, the following packaging composition meets both the inerting and maximum weight of contents requirements:

	Volume (ft^3)	Weight (lb)
Dry sand	4.69	673
DU	0.46	535
Interparticle voids	2.20	
Total	7.35 (55 gallon)	1208

The void space of 2.20 ft^3 is equal to 30 percent of the total volume and is about what may be expected between loosely packed particles. The DU volume in this package is 9 percent of the total solids volume and therefore meets the selected inerting requirement. On a mass basis, the maximum allowable DU in the package is 44 percent.

B. PACKAGING COSTS AND METHODS

The packaging process includes all operations falling between removing the sand from the test butt to loading drums on trucks for transportation to a low-level radioactive waste repository. For the current operation (Option 0), this includes adding cement and water to form concrete, pouring it in DOT-approved Type-A containers, and in some cases adding DU fragments to the concrete mix.

1. Packaging Costs for Option 0 (Fixation in Concrete)

The primary source for cost data for fixation in concrete is the actual costs incurred in the 1986 cleanup effort. CNSI processed 3369 55-gallon drums of contaminated sand.[5] The actual cost for packaging and transportation was $668,000, with an additional $46.25 for the cost of each container. Of the $668,000, approximately $164,800 was for transportation, leaving a net packaging cost of $503,200 for 3369 55-gallon drums. An additional $150,000 was charged to the project by Martin Marietta Energy Systems for monitoring contractor operations during the packaging process.[6] Therefore, the unit packaging cost by fixation in concrete as performed in the operation may be estimated as follows:

Unit packaging cost =

$$\frac{\$503{,}200(\mathit{packaging}) + \$150{,}000(\mathit{QA})}{3369(\mathit{drums})7.35)(ft^3/\mathit{drum})}$$

$$+ \frac{\$46.25/\mathit{drum}}{7.35(ft^3/\mathit{drum})} \cdot \frac{1.06\,ft^3\mathit{waste}^*}{ft^3\mathit{sand}}$$

$= \$33.1/ft^3.$

*Estimated increase in waste volume due to addition of mo... and water

2. Packaging Costs for Options 1 Through 5

A lower-cost packaging procedure is assumed for Options 1 through 5; this consists of inerting with sand, drying to less than 0.5 percent moisture, as required for burial, and sealing in a Type-A container. The application varies somewhat in each option. Therefore, the packaging process for Option 1 will be used to determine unit labor costs, which will be assumed to apply to the other cases. For Option 1, the packaging procedure consists of the following steps: (1) delivery of the contaminated sand to a hopper by front end loader, (2) transporting to a drier/cooler by screw conveyor, (3) transporting to the screen by screw conveyor, (4) combining fragment and fines output flow from the screen directly into 55-gallon drums, and (5) sealing and transporting the drums by forklift to a storage area.

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5 T.H. Hodgens, Chem-Nuclear Systems, Inc., letter to A. L. Porell, Martin Marietta Energy Systems, regarding Subcontract 228-22251V, October 13, 1986.

6. A. L. Porell, Martin Marietta Energy Systems, Inc., personal notes on the sand/DU disposal project, 1987.

Unit labor costs for each type of operation as incurred in the 1986 cleanup operation are listed in Table A-1. Indirect costs are estimated as twice the employees' salaries, and the G&A charge is estimated as 20 percent of the direct plus indirect labor cost. Thus, the total labor cost for the packaging crew comes to \$204/hour.

A total operation time of 30 hours for packaging is estimated, based on the equipment size specified in Table 3 plus an additional 16 hours for start-up and shutdown. Therefore, total labor costs for the operation are estimated as follows:

Labor	(46 h)	(\$204/h)	=	\$ 9,400
QA	(46 h)	(\$ 70/h)	=	\$ 3,220
Administrative	(5 d)	(\$120/d)	=	\$ 600
	Total labor		=	\$13,420

Therefore, the labor cost per cubic foot of processed sand is

$$\frac{\$13,420}{(30)\cdot(27 ft^3/h)} = \$16.6/ft^3$$

assuming a 27-ft^3/h processing rate of fines appropriate for the selected equipment size. The drum cost per cubic foot of sand is

$$\frac{\$46.25/drum}{7.35(ft^3/h)} = \$6.3/ft^3$$

Therefore, the total unit packaging cost is estimated to be \$16.6/ft^3 + \$6.3/ft^3 = \$22.9/ft^3.

TABLE A-1. ASSUMED LABOR RATES FOR PACKAGING OPERATIONS

Operation	Type of Worker	Direct Labor	Cost ($/hour)		
Supervision	Foreman (1/2 time)	(1/2)	($12.30/hr)	=	$ 6.15
Radiation control	Health Physicist	(1)	($12.15/hr)	=	$12.15
Forklift driver	Operator	(1)	($13.10/hr)	=	$13.10
Drumming	Operator	(1)	($13.10/hr)	=	$13.10
Sampling/general relief	Operator	(1)	($12.15/hr)	=	$12.15
Total Direct					$56.65/hr

Direct	=	$ 56.65
Indirect	=	$113.30
G&A	=	$ 34.00
Total	=	$203.95

C. TRANSPORTATION COSTS

The cost of transporting packaged waste from Eglin AFB to Barnwell, South Carolina, is projected to be $\$4.1/ft^3$ in 1989 dollars. This estimate is based on costs incurred by CNSI during the 1986 cleanup efforts. The underlying assumptions are as follows:

1. Trucks will continue to be used to transport the contaminated sand.

2. Most of the material will continue to be packaged in 55 gallon drums.

3. The shipments are limited by volume rather than by mass.

The basis for the estimate is that the 1986 CNSI proposal included \$164,830 for shipping 45,590 ft^3 of waste to Barnwell.[7] The cost of shipping has escalated ~4 percent/year since 1986.[8] Therefore, the 1989 cost of shipping large quantities of packaged waste material is approximately

$$\$164{,}830/45{,}590\ ft^3 \times (1.04)^3 = \$4.1/ft^3.$$

An independent estimate can be made based on data provided by NUS Services in 1985.[9] NUS estimated \$1.42/mile for shipping the material at Eglin AFB. Assuming 45 drums/truck, 7.3 ft^3 of waste per drum, and 457 one-way miles per trip, the NUS cost is:

$$[\$1.42/\text{mile} \times (457 \times 2)\ \text{miles/trip}]/(45\ \text{drums/truck} \times 7.3\ ft^3/\text{drum}) \times (1.04)^4 = \$4.6/ft^3.$$

D. BURIAL COSTS AND ESCALATION

The largest single cost element in the 1986 cleanup effort was burial at the radiological waste repository at Barnwell,

7 R. J. Lynn, Martin Marietta Energy Systems, Inc., letter to A. L. Porell, Martin Marietta Energy Systems, regarding Subcontract No. 22X-22251V, April 15, 1987.

8 R. Betot, NUS Pr[illegible] Services Corporation, Columbia, South Carolina, personal communication to W. M. Bradshaw, Martin Marietta E[illegible]rgy Systems, Inc. March 17, 1989.

9 W. Nipsher, NUS Process Services Corporation, Columbia, South Carolina, personal communication to C. B. Oland, Martin Marietta Energy Systems, Inc., [illegible]ugust 1, 1985.

South Carolina. Through its contractor, the Air Force paid ~$28/ft^3 and $31.5/ft^3 in 1986 and 1987, respectively. The base disposal charge for standard waste at Barnwell is given in Table A-2.

TABLE A-2. BASE DISPOSAL CHARGE FOR STANDARD WASTE AT BARNWELL, SOUTH CAROLINA

YEAR	COST (\$/ft^3)
1985	24.94
1986	28.00
1987	31.50
1989	36.87

The cost of disposal is going up faster than general inflation. The data in Table A-2 represent a 10 percent annual escalation rate, of which ~4 percent is due to general inflation. Step changes in the disposal rate will drive the real cost even higher. Barnwell is scheduled to be shut down at the end of 1992. An additional tax of $10/ft^3 will be added in 1990 to help fund the development of an above-ground facility to replace Barnwell.[10] Estimates for the new facility range from $80/ft^3 to $120/ft^3.[11]

The computer model used to analyze the options listed in Section 3 includes parameters for the current burial cost, an estimate of the real escalation rate, a projected disposal cost for the above-ground facility, and the year that Barnwell shuts down (and the new facility comes on-line). The basic data used and the range used in sensitivity analysis (where appropriate) are given in Table A-3.

E. DU RECYCLE

Approximately 80 percent (by mass) of the DU fired into the test butt is removed in coarse screening as fragments. There is a possibility that the larger fragments (>4-mesh) could be returned to the manufacturing process.

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10 R. Johnson, Chem-Nuclear Systems, Inc., Columbia, South Carolina, personal communication to R. P. Wichner, Martin Marietta Energy Systems, Inc., February 22, 1989.

11 R. Johnson, Chem-Nuclear Systems, Inc., Columbia, South Carolina, personal communication to R. P. Wichner, Martin Marietta Energy Systems, Inc., February 22, 1989.

TABLE A-3. BURIAL COST DATA USED IN THE ECONOMIC ANALYSIS

ITEM	VALUE	RANGE
Base charge (Barnwell)	\$36.87/ft^3	Not Considered
Taxes	2/4% of base	Not Considered
Real escalation rate	6%	
Base charge (new facility)	100/ft^3	\$100-\$400/ft^3
Year Barnwell is shut down	1992	Not Considered

The material used to make DU penetrators is provided by several contractors, including the Aerojet-General plant in Jonesborough, Tennessee. The Aerojet plant reduces depleted UF_4 (green salt) to metallic uranium. They are also capable of recycling DU and in limited cases have recycled DU that is damaged in producing 30-mm rounds.[12]

As part of a separate but related project, Bob Sharp of Aerojet visited Eglin AFB to determine if any of the DU fragments could be recycled.[13] Sharp's conclusions were as follows:

1. The silicon content in the DU was too high to meet DOD specifications for DU munitions; however, the silicon content was satisfactory for use as ballast material.

2. If the iron concentration the DU fragments exceeds 400-600 ppm (by mass), the material could not economically be reused by Aerojet.

3. Excessive quantities of DU fragments could not be processed by Aerojet because of the relatively high rate of NOx production during the initial surface cleaning (pickling

12. P. O'Donovan, Aerojet-General, Inc., San Bernardino, California, personal communication to W. M. Bradshaw, Martin Marietta Energy Systems, Inc., March 13, 1989.

13. R. Sharp and W. Hendershott, Aerojet-General, Inc., Jonesborough, Tennessee, personal communication to W. M. Bradshaw, Martin Marietta Energy Systems, Inc., February 15, 1989.

with nitric acid). However, Aerojet plans to upgrade their NOx scrubbers within a year; so the fines limitation may not be a problem.

4. After surface cleaning, the DU fragments could possibly be melted and used by Aerojet for ballast applications.

5. Aerojet would have to analyze the fragments and test their processing characteristics before agreeing to accept fragments for recycle.

A 1982 study to determine the feasibility of recycling DU fragments indicates that recycled DU material may meet the specifications for manufacture of GAU-8 penetrators (Reference A-1). The recycle process described by Waltz is shown in Figure A-1. Three 800-kg DU billets were cast which met the requirements for DU penetrators. The Honeywell specifications and the chemistry for the three billets as given in Waltz's report are given in Table A-4. Waltz did not include cost data in his report.

The DOE internal value of depleted UF_6 is only \$2.50/kg DU. However, at the Oak Ridge Y-12 Plant, it costs \$200/kg DU to reduce the UF_6 to metallic uranium.[14] Therefore, the internal DOE value of metallic DU at Y-12 is \$202.5/kg. Because of larger production rates, the cost of reducing the material to metallic uranium is probably less at the Aerojet facility.

The cost of packaging and transporting DU fragments to a DU manufacturing facility (e.g., Aerojet-General) exceeds \$2.50/kg but is probably less than \$50/kg. The cost of removing surface contamination and preparing DU fragments for the production process is unknown. In all likelihood, the "best case" is that the Air Force could pay for packaging and shipping and that the DU processing facility would accept the fragments at no charge.

DU recycle has been included within Option 2. The primary cost savings from recycle results from decreased burial volume. However, the volume of the DU fragments is so small (typically <1 percent of the volume of sand fines) that recycle of the fragments may not be cost-effective at the \$202.5/kg resale value for metallic DU. Moreover, recycle will have an initial development cost to determine if the fragments can be reused by the DU manufacturer (which has not been included in the cost estimate).

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14 J. Russell, DOE-ORO, personal communication with W. M. Bradshaw, Martin Marietta Energy Systems, Inc., October 7, 1988.

However, there are noneconomic reasons that favor recycle in that it supports Air Force objectives to minimize the generation of hazardous and radiological waste. A detailed analysis of the processing requirements, packaging and transportation costs, and noneconomic impacts of DU recycle should be performed prior to committing to the recycle of DU fragments.

F. REFERENCES FOR APPENDIX A

A-1. M. J. Waltz, DU Test Range Fragment Reclamation, AFATL-TR-82-49, Air Force Armament Laboratory, 1982.

TABLE A-4. CHEMISTRY OF DU BILLETS MADE FROM DU FRAGMENTS RECOVERED FROM EGLIN AFB TEST BUTT (REFERENCE 8)

Element	Maximum Desired level (ppm)	Possible level (ppm)	Range for test billets (ppm)[a] Billet UX7194	Billet UX7292	Billet UX7383
Ti	7500 ± 1000	7500 ± 1000	7300 - 7400	7400 - 7500	7400 - 7700
C	300	300	40 - 50	40 - 70	40 - 50
H_2	15	15	b	b	b
O_2	300	300	b	33	27
Ni	150	150	b	b	b
Cu	65	65	2 - 3	5 - 6	6 - 7
Si	125	125	39 - 45	75 - 83	80 - 85
Fe	300	300	160	85 - 89	74 - 77
Al	c	c	22 - 25	19 - 21	37 - 38
Other[d]	50	50	c	c	c

[a]Range for three samples taken at top, middle, and bottom of billet.
[b]Analysis not performed.
[c]Not reported.
[d]Includes aluminum.

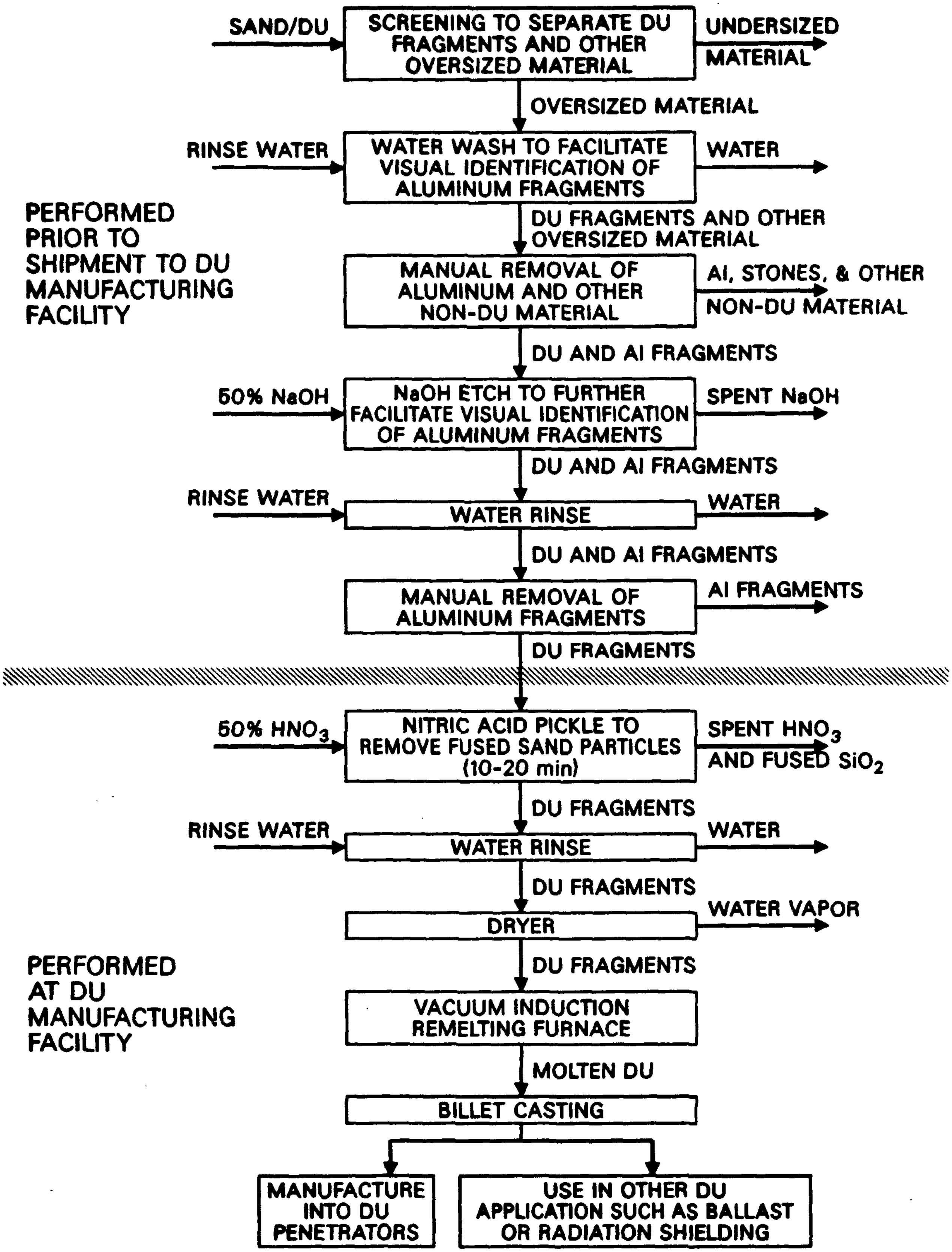

Figure A-1. Flow Sheet for DU Recycle Process (Reference 8).

APPENDIX B
SCREENING EQUIPMENT AND COST

A. SCREENING CAPITAL COST AND PROCEDURE

Screening tests performed under subcontract by K D Engineering provide the basis for the selection of the screening equipment. Test results are provided in a Phase 2 report (Reference B-1). The selected screening apparatus will likely be of the cylindrical, central top-loader type with replaceable steel screens. Size cuts, taken at the 10-mesh and 60-mesh sizes, provide three outlet flows, +10, -10/+60 and -60-mesh. Additional internal screens are required to allow a smooth flow of material screen-to-screen.

The principal screening problem is the effect of moisture on the capability of performing the 60-mesh step. It was found (Reference B-1) that while 1.7 percent moisture in the feed screened satisfactorily, slightly higher moisture levels jammed the 60-mesh screen. Therefore, a drier is required in the feed line. Transportation regulations require that loose contents in Type-A containers be dry. Therefore, a drier is required in any case as a prepackaging requirement.

A preliminary estimate of the screening system capital costs, sized for Option 1, is provided in Table 3. The screening system consists of a feed hopper; variable-speed screw conveyers to and from the drier; and a 5 foot diameter, central top-loaded vibrating screen with outlet chutes, one of which feeds a stack loader. The stack loader feeds the recycle size range (-10/60-mesh) to an appropriate storage area, where a front-end loader may pick up and return the sand to the butt. The entire assemblage operates under a slight negative pressure so that dust generated during the operation is not released. Each component is sealed and has one or more ports where it is connected to the baghouse collection duct. The baghouse is equipped with a HEPA filter on the exhaust stack which will capture any particulate material not contained by the baghouse filters.

B. OPERATIONAL COSTS FOR SCREENING

Costs for screening operations that are not associated with a simultaneous packaging step are estimated in this section. For other cases, where the screening operation is one of a series of operations ending in packaging, the screening cost is included in the packaging cost, as estimated in Appendix A, Section B.

1. Screening Costs for Option 0

The current operation uses a 1/2-inch screen owned by the Air Force. Start-up, operation, and shutdown require two operators, two health physicists (HPs), and a supervisor for 5 days. The labor rates, indirect cost ratios, and G&A cost assumptions have been extracted from the 1986 CNSI proposal to assure continuity in cost estimates.

Therefore, the cost of screening 75 percent of the entire butt (8250 ft^3) is as follows:

(4 operators) ($13.1/h) (40h)	=	$ 2,306
(2 HPs)($12.15/h)(40h)	=	972
(1 supervisor)($12.3/h)(40h)	=	492
Total direct labor cost		$ 3,770
Indirect labor cost (2X direct)		7,540
G&A (20 percent of direct + indirect)		2,262
Total cost		$ 13,600

The cost of screening is therefore

$$\frac{\$13,600}{8250\ ft^3} = \$\ 1.6\ /ft^3$$

2. Screening Costs - Options 1-4

Options 1 to 4 call for a higher-capacity screening device capable of processing 270 ft^3/h feed (as opposed to 100-125 ft^3/h for the current operation). Moreover, it seems feasible that a maximum of 75 percent of the butt requires screening in a given cleanup operation; so the new equipment can accomplish the screening operation in

$$\frac{(11,000\ ft^3\ \text{sand})\ (0.75\ \text{removed})}{270\ ft^3\ /h} = 30\ \text{hours}$$

Assuming 16 hours for start-up and shutdown, the total time the screening crew will be on-site is 46 hours. The crew consists of four operators, one each for the front-end loader, dryer feed conveyor, screen, and stacker, two health physicists, and a supervisor. Therefore, the cost of a screening operation would be

(4 operators)($13.1/h)(46h)	=	$2,410
(2 HPs)($12.15/h)(46 h)	=	1,118
(1 supervisor)($12.3/h)(46 h)	=	566
Total direct labor cost		$ 4,094
Indirect labor cost (2X direct)		8,188
G&A (20 percent of direct and indirect)		2,456
Total cost		$14,738

The unit cost of screening for Options 1 to 4 is therefore

$$\frac{\$14,738}{8250\ ft^3\ \text{screened}} = \$\ 1.8\ /ft^3$$

C. REFERENCES FOR APPENDIX B

B-1. J. M. Keane, K D Engineering, Phase II Subcontract Report to Oak Ridge National Laboratory (DRAFT), June 1989.